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THESIS

SMALL BOAT AND SWARM DEFENSE: A GAP STUDY

by

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September 2008

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13. ABSTRACT (maximum 200 words)

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This thesis shows that a gap in capability exists in the surface force to defend itself against small threat craft. It adds functionality to the Anti-Terrorism / Force Protection (AT/FP) Tool initially developed by Lieutenant James Harney (Harney 2003) and significantly enhanced by Lieutenant Patrick Sullivan (Sullivan 2006). Lieutenant Harney created the foundation for all the work that followed by investigating the role of Discrete Event Simulation (DES) in defense Modeling and Simulation (M&S). The result of this work was "a fully integrated, prototypical, Java-based application that demonstrates how various Open-Source, web-based technologies can be applied in order to provide the tactical operator with tools to aid in Force Protection planning" (Harney 2003). Following Lieutenant Harney, Lieutenant Sullivan added a great deal of functionality to the system by "providing the ability to evaluate security alternatives utilizing models of force protection assets, existing naval facilities, and terrorist agents" in a 3-D virtual environment with data collection for output analysis (Sullivan 2006).

My work further expands the simulation's capabilities by adding the functionality to simulate small boat and swarm attacks against underway Arleigh Burke Class Guided Missile Destroyers (DDGs) conducting straits transits using variable, realistic Artificial Intelligence (AI). The additional tools were designed specifically to evaluate current weapons and tactics by collecting data on saturation of crew-served weapons, engagement timelines, and lines of approach. This allows future researchers to evaluate the effectiveness of prototype sensors, weapons, and tactics visually or through output analysis in order to make more informed decisions regarding systems acquisition or doctrinal changes.

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SMALL BOAT AND SWARM DEFENSE: A GAP STUDY

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My work further expands the simulation's capabilities by adding the functionality to simulate small boat and swarm attacks against underway Arleigh Burke Class Guided Missile Destroyers (DDGs) conducting straits transits using variable, realistic Artificial

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ACRONYMS AND ABBREVIATIONS

A*	A Star
AI	Artificial Intelligence
AMM	Avoidance Mover Manager
API	Application Programming Interface
AT/FP	Anti-Terrorism / Force Protection
ATG	Afloat Training Group
CAT	Crisis Action Team
CCR	Continuous Certification Requirement
CIC	Combat Information Center
CO	Commanding Officer
CG	Guided Missile Cruiser
CSW	Crew Served Weapons
C2	Command and Control
DIS	Distributed Interactive Simulation
DES	Discrete Event Simulation
DDG	Arleigh Burke Class Destroyer
DOD	Department of Defense
DOE	Design of Experiments
DON	Department of the Navy
DIS	Distributed Interactive Simulation
ELV	Explosive Laden Vessel
EOD	Explosive Ordinance Disposal
ESPDU	Entity State Protocol Data Unit
FAC	Fast Attack Craft
FFG	Guided Missile Frigate
FIAC	Fast Intruder Attack Craft
FPAO	Force Protection Action Officer
FPCON	Force Protection Condition
FSA	Finite State Automata
GQ	General Quarters (Battle Stations)

GUI	Graphical User Interface
GWOT	Global War on Terrorism
HLL	High Level Language
HTML	Hypertext Markup Language
IDE	Integrated Development Environment
IMM	Intercept Mover Manager
IEEE	Institute of Electrical and Electronics Engineers
IRGCN	Islamic Revolutionary Guard Corps Navy
JAXB	Java Architecture for XML Binding
Java VM	Java Virtual Machine
JDK	Java Development Kit
JDOM	Java Document Object Model
JPEG	Joint Photographic Experts Group
JRE	Java Runtime Environment
LCAC	Landing Craft Air Cushioned
LSVE	Large-scale Virtual Environment
M&S	Modeling and Simulation
MAS	Multi-Agent Systems
MOE	Measure of Effectiveness
MOP	Measure of Performance
MPC	Military Patrol Craft
NPS	Naval Postgraduate School
OOD	Officer of the Deck
PCL	Property Change Listener
PNG	Portable Network Graphics
RHIB	Rigid Hull Inflatable Boat
ROE	Rules Of Engagement
SAVAGE	Scenario Authoring and Visualization for Advanced Graphical Environments
SLOC	Sea Line of Communication
SMAL	Savage Modeling Analysis Language
SME	Subject Matter Expert

SSDF	Ship Self Defense Force
TAO	Tactical Action Officer
TCP	Terrorist Cell Planner
TFOM	Training Figure of Merit
TORIS	Training and Operational Readiness Information Services
USV	Unmanned Surface Vehicle
VRML	Virtual Reality Markup Language
W3C	World Wide Web Consortium
X3D	Extensible 3D Graphics Standard
XML	Extensible Markup Language
XMSF	Extensible Modeling and Simulation Framework
XO	Executive Officer
XSLT	Extensible Stylesheet Language for Transformations
ZMM	Zone Mover Manager

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I. INTRODUCTION

> I can imagine no more rewarding a career. And any man who may be asked in this century what he did to make his life worthwhile, I think can respond with a good deal of pride and satisfaction: 'I served in the United States Navy.'
>
> \- President John F. Kennedy

A. PROBLEM STATEMENT

U.S. Naval forces conducting straits transits face a host of unique force protection challenges. Traffic density is often high, with many ferries, fishing and pleasure boats, and large cargo ships maneuvering in a small area. Although the Rules of Engagement (ROE) will generally designate query and warning ranges, International law and freedom of navigation allow vessels to operate in very close proximity to warships. Small vessels are often difficult to regulate and many lack basic equipment such as bridge to bridge radios. With a host of stationary and seemingly randomly moving boats, determining a hostile action in a timely manner is difficult at best. These conditions make the identification of and defense against hostile small craft extremely difficult. Even after a craft is designated hostile the timeline for mounting an effective defense is often very short.

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the system by "providing the ability to evaluate security alternatives utilizing models of force protection assets, existing naval facilities, and terrorist agents" in a 3-D virtual environment with data collection for output analysis (Sullivan 2006).

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B. PERSONAL EXPERIENCE

As a U.S. Navy Surface Warfare Officer, I have served two afloat tours. The first was on an Arleigh Burke Guided Missile Destroyer (DDG), and the second was an afloat Command Staff. During both tours I had the opportunity to see how Crew Served Weapons operated, how training was conducted, how the chain of command was set up, and the tactics we and others employed for combating small boat and swarm attacks.

One of the most startling examples of effective swarm tactics that I have ever seen occurred during a Midshipmen tour with the Norwegian Navy. I was stationed for a month on a Norwegian fast patrol boat. During a NATO exercise, the Norwegians positioned 24 such patrol boats, each equipped with two torpedoes, just behind a series of rocky outcroppings on the coast of Norway. From this vantage point we stood on the top of the patrol boat's pilot house and watched for the masts of passing NATO ships. When an American aircraft carrier came into view, the order was given for all 24 patrol boats to launch a simultaneous attack. All boats headed straight for the carrier at a flank bell and when within range, all fired both simulated torpedoes. The patrol boats then immediately turned and ran back to the fjords and safety. The NATO forces' radars were unable to detect any of the patrol boats mixed in with the jagged rocks and they had no warning of

the coming attack. The attack was so fierce and quickly executed that the NATO forces had almost no chance to mount an effective defense and the majority of the torpedoes were reported as hits by the exercise proctors.

One other event worth noting took place during my tour on the DDG. We received a distress call from a burning vessel and responded. When we arrived on the scene, a small sport fishing vessel was ablaze and two men were a short distance away in a life raft. The men were brought aboard via one of our Rigid Hull Inflatable Boats (RHIB) where they were met by our Commanding Officer (CO). After a failed attempt to extinguish the fire using shipboard fire hoses, the CO informed the owner that we were required to sink the vessel as it posed an uncharted hazard to navigation and the owner agreed. We then manned up all of our Crew Served Weapons (CSW) on one side of the ship, including the 25mm chain gun and .50 cal mounts and began to fire on the boat. Despite numerous direct hits the boat showed no signs of sinking and not wanting to waste ammunition the CO ordered the gunners to stand down. The vessel eventually burned to the waterline and sank.

On both occasions I realized that I had just witnessed a significant event take place, and those experiences were some of the driving forces behind my involvement in this thesis. In neither case can I assign any blame to any personnel or equipment failures. The outcomes were derived not by the fault of anyone or anything. Personnel followed orders, sensors and weapons worked correctly, but we are ill prepared and ill equipped to deal with small boat and swarm threats.

C. OVERVIEW

The vulnerability of U.S. warships conducting straits transits has long been a concern for the United States Navy. Restrictions in the ROE as well as requirements imposed by innocent and transit passage allow potential adversaries unique opportunities to test both our engagement criteria and capabilities. On January 6, 2008, this was demonstrated in the Straits of Hormuz when a group of suspected Islamic Revolutionary Guard Corps Navy (IRGCN) vessels approached and harassed the USS Port Royal (CG 73), USS Hopper (DDG 70) and USS Ingraham (FFG 61) as they transited the straits.

The small boats made high speed approaches, attempted to interfere with navigation, and discarded boxes into the water in front of the warships. Additionally, verbal threats were received over the bridge to bridge radio that may have originated from a shore based transmitter. This example clearly demonstrates the challenges facing Commanders in these situations. Ultimately no shots were fired and the situation ended peacefully, but not before getting the attention of the highest levels of the U.S. government.

Figure 1. Image of suspected IRCGN vessels in Straits of Hormuz Jan 6 2008 (from http://www.navy.mil/view_single.asp?id=54340)

While this scenario demonstrates some of the problems associated with force protection, it is far from a worst case scenario. In this case the vessels were marked as IRGCN and were using bridge to bridge radios. A far more complex situation would involve unmarked craft or craft that appear to be fishing or pleasure boats that do not respond on bridge to bridge. The fact that any vessel has the potential to be a threat makes identifying an adversary the equivalent not to finding a needle in a haystack, but rather to finding one specific needle in a stack of needles.

D. CHALLENGES

In order to understand the challenges to force protection in straits transits it is important to first understand the physical constraints placed on a vessel conducting such a transit. Many straits commonly navigated by U.S. warships are less than ten nautical miles wide. Assuming that the channel or traffic separation scheme is in the center or near the center of this waterway means that land is less than five nautical miles from either side of the ship. Even more restrictive is the fact that a good portion of the strait may not have sufficient draft so as to be navigable to larger vessels and the navigable waters are often broken up into traffic separation schemes. Close proximity to land also interferes with both surface and air search radars as the surface picture suffers from false echoes from land based structures and air radars must be either attenuated or turned off altogether in order not to interfere with ground based electronics.

Straits are often strategically important because they serve as hubs for commercial traffic. This traffic may include tankers, large merchant ships, ferries, fishing, and maintenance vessels and civilian pleasure craft. High surface traffic density makes identification and tracking of individual craft very difficult. While U.S. Sailors are trained in the U.S. Coast Guard's Rules of the Road (Coast Guard 2005), merchant traffic, and to a greater extent civilians, routinely ignore these regulations. This makes predicting the actions of another vessel difficult and further complicates distinguishing hostile intent or action. Table 1 describes some of the world's busiest oil relevant straits in terms of traffic, geographic restrictions, and past problems.

Important World Oil Transit Chokepoints						
Name	**2006E oil flow (bbl/d)**	**Width at Narrowest Point**	**Oil Source Origin**	**Primary Destination**	**Past Disturbances**	**Alternative Routes**
The Strait of Hormuz	16.5-17 million	21 miles	Persian Gulf Nations including Saudi Arabia, Iran, and UAE	Japan, The United States, Western Europe, other Asian countries	Sea mines were installed during the Iran-Iraq War in the 1980s. Terrorists threats post September 11, 2001.	745-mile long East-West Pipeline through Saudi Arabia to the Red Sea
The Strait of Malacca	15 million	1.7 miles	Persian Gulf Nations, West Africa	All Asia/ Pacific consumers including Japan and China	Disruptions from pirates are a constant threat, including a terrorist attack in 2003. Collisions and oil spills are also a problem. Poor visibility from smoke haze.	Reroute through the Lombok or Sunda Strait in Indonesia. Possible pipeline construction between Malaysia and Thailand.
The Suez Canal/ Sumed Pipeline	4.5 million	1,000 feet	Persian Gulf Nations, especially Saudi Arabia, and Asia	Europe and The United States	Suez Canal was closed for eight years after the Six-Day War in 1967. Two large oil tankers ran aground in 2007 suspending traffic.	Reroute around the southern tip of Africa (the Cape of Good Hope); additional 6,000 miles.
Bab el-Mandab	3.3 million	18 miles	The Persian Gulf	Europe and The United States	USS Cole attack in 2000; French oil tanker in 2002, both attacks off the coast of Aden, Yemen	Northbound traffic can use the East-West oil pipeline through Saudi Arabia; Reroute around the southern tip of Africa (the Cape of Good Hope); additional 6,000 miles.
The Turkish Straits	2.4 million	0.5 mile	Caspian Sea Region	Western and Southern Europe	Numerous past shipping accidents due to the straits sinuous geography. Some terrorist threats were made after September 11, 2001.	No clear alternative; potential pipelines discussed including a 173-mile pipeline between Russia, Bulgaria, and Greece.
The Panama Canal	0.5 million	110 feet	The United States	The United States, and other Central American countries	Suspected terrorist target	Reroute around Straits of Magellan, Cape Horn and Drake Passage; additional 8,000 miles

Figure 2. Important World Oil Transit Chokepoints (from http://www.eia.doe.gov/cabs/World_Oil_Transit_Chokepoints/Background.html)

The number one enemy to a Commander attempting to protect his ship against small boat attack is time. It is central to the problem because many factors compress reaction times in these situations. Among these factors are physical speed, geographic separation, identification, and maneuverability. Current doctrine for straits transits generally dictates that the faster a strait transit can be accomplished the better. Unfortunately when dealing with small craft, this may equate to closure rates in excess of 50kts or 84.47 Feet per Second. Assuming that an unmarked vessel loitered in traffic until it was 500 feet from a U.S. warship before accelerating towards the ship at max speed the small boat would reach the ship in 5.91 seconds.

As mentioned earlier, identification of threats prior to the onset of hostile action is nearly impossible. The attack on the USS Cole in Aden Harbor, Yemen on October 12, 2000 demonstrates this point (CRS 2001). Unmarked vessels conducting what amounts to maritime guerilla warfare render whole suites of sophisticated sensors irrelevant. In congested waterways the normal markers for hostile intent (closure rate, erratic maneuvering, proximity, etc) are also negated as chaotic traffic is constantly moving in multiple directions. Maintaining Situational Awareness (SA) is a problem for both bridge watch standers and the personnel manning the Combat Information Center (CIC) as the number, type, and intent of surface vessels quickly becomes overwhelming.

Adding to the confusion and stress inherent in straits transits is the issue of limited maneuverability. The current practice of high speed transits coupled with narrow waterways means that only small rudder adjustments are possible and warships are extremely limited in their ability to execute evasive maneuvers or maneuver to unmask batteries. Even in the best of situations where the only concern is safe navigation, maintaining a safe distance from neutral shipping is often problematic.

E. OBJECTIVES

The objective of this thesis is to identify current gaps in force protection against small boat attack during swarm attacks. This will be accomplished by conducting unclassified simulations examining current doctrine against multiple types of enemy tactics, examining current training methodology and equipment, and researching possible

systems, techniques, and equipment to enhance our future capabilities. Simulation tools developed at NPS will be used to run a series of visual simulations with output data analysis.

F. THESIS ORGANIZATION

Chapter II consists of literature review and current methodology for training and equipment. This chapter explores how the U.S. Navy trains at sea personnel, as well as the capabilities and limitations of current crew-served weapons. Additionally, Chapter II explores possible future training systems. Chapter III gives examples of previous related work and will go step by step through the software used to develop and run the scenario. Each piece of software will be described ensuring a baseline understanding of how the simulation was created. Chapter IV describes the modeling approach with respect to behaviors of simulated entities and creation of the test scenario. Chapter V contains detail analysis and conclusions and Chapter VI contains recommendations for future work.

II. LITERATURE REVIEW

> I have spread the mantle of my nation over the ocean, and will guard her forever. I am her heritage, and yours. I am the American Sailor.
>
> -Anon

A. INTRODUCTION

This chapter covers current weapons employed onboard U.S. naval warships, in particular those onboard the Arleigh Burke Class Guided Missile Destroyer (DDG), as well as current training methods as prescribed by the Surface Force Training Manual (DON 2007). Additionally, some metrics for small boat threat craft and corvettes will be included. Of particular relevance is the lack of any qualification for an underway vessel to repel a coordinated small boat attack. Additionally, the only live fire exercises prescribed for afloat units involve firing either at stationary targets at a range or firing on floating targets at sea. As noted below, there are requirements to repel a small boat at a pier and at anchor. However, the methodology for the set up and conduct of these qualifications are sparsely documented. This is due to the fact that to date, no training system exists to adequately train for these scenarios.

B. SURFACE FORCE TRAINING MANUAL

1. Reporting Tools and Requirements

Commander Naval Surface Forces (COMNAVSURFOR) instruction 3502.1D Surface Warfare Training Manual (SURFORTRAMAN) released July 1, 2007 is the current U.S. fleet standard for the training and qualification of surface vessels and crews. This instruction details the requirements for surface force qualification and certification in all warfare areas, force protection, and damage control. Most notable regarding revision D to this instruction is the introduction of the SHIPTRAIN methodology for training and readiness. SHIPTRAIN effectively removes the previous method of having cyclic standard training for ships crews by shore based agencies such as Afloat Training

Groups (ATG). Instead, ships complete an initial series of certifications after which, they self report and self assess and request augmented training as required (DON 2007). This greatly increases the burden on ships training teams to not only train effectively, but also to honestly report degradation in mission areas to organizations outside of the command. Figure 3 illustrates the SHIPTRAIN cycle of training, assessing, and reporting.

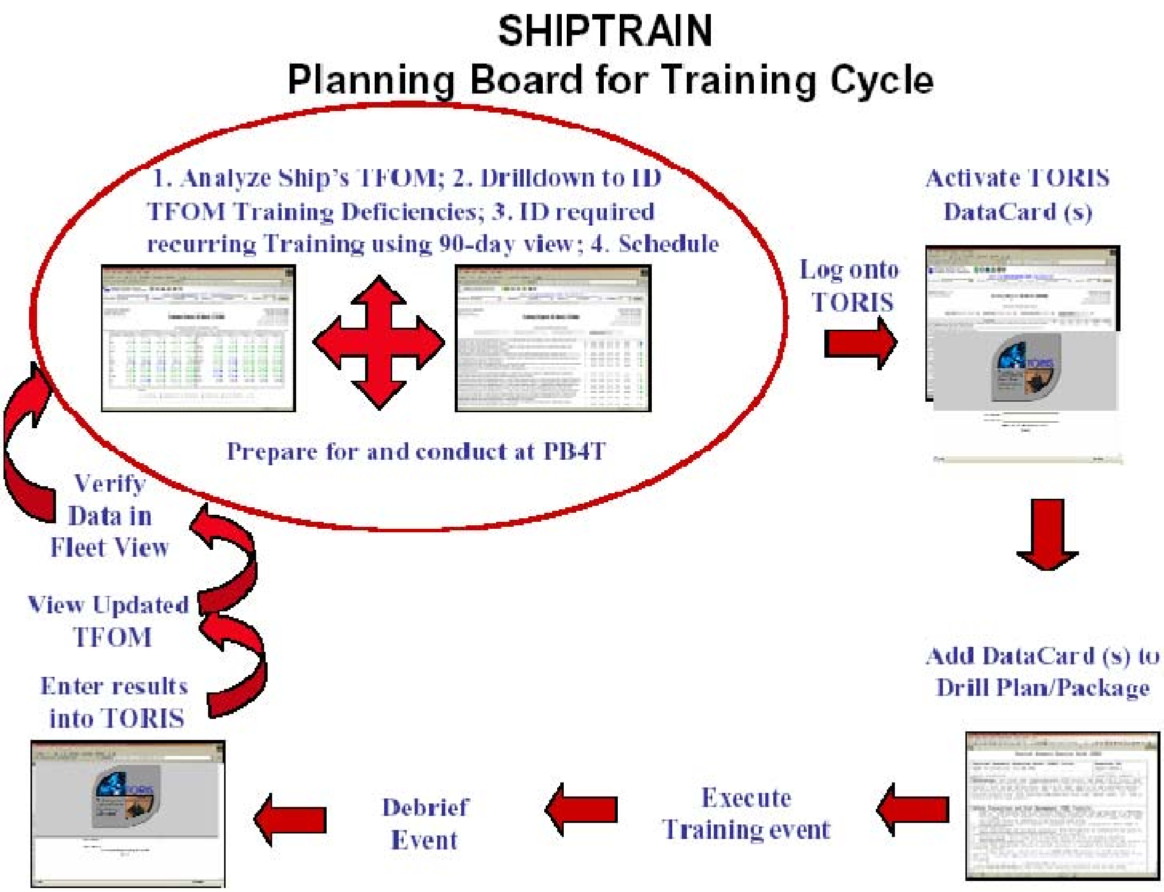

Figure 3. SHIPTRAIN training and reporting cycle. (DON 2007)

The SHIPTRAIN method was introduced in response to the fleet's adoption of the Fleet Response Program (FRP) designed to create a more responsive, flexible, force that is ready to deploy far more often than under the previous 18 month training cycle. Along with SHIPTRAIN, the current SURFORTRAMAN mandates the use of two new systems

to the fleet: the Training and Operational Readiness Information Services (TORIS) and the Training Figure of Merit (TFOM). TORIS is a new electronic reporting system used by force commanders to have a quick reference overview of an individual unit's current status with regards to readiness and capabilities. TORIS reports are generated using a series of TFOM reports. TFOM is a metric for evaluating how a unit is performing in a specific mission area or on a specific training exercise or event. Ship's training officers receive reports from shipboard training teams evaluating performance and report these using TORIS.

2. Antiterrorism and Force Protection Qualifications

Tab C of the SURFORTRAMAN delineates the requirements for AT/FP qualification at the unit level. Within this section, the only mention of small boat defense comes in the form of the tenth Continuous Certification Requirement (CCR). The current fleet standard for certifying this CCR is essentially a communications and FPCON drill. A watch stander in a training environment is approached by a proctor and shown a photo of a small boat and told that it is approaching the ship. From that point, the watch stander talks his or her way through the appropriate FP measure but never touches a weapon. While knowing the appropriate steps, in the event of an emergency, is indeed important it does not train the watch stander to functionally and physically engage a target. Training to repel a small boat attack with a photo and verbal commands is akin to expecting someone to swim during a crisis when their only training has been in a classroom. There are certain skills that require a hands-on approach to successfully master. Note the safety section below the chart in Figure 4 that mandates that all small arms will be replicas and that all CSW will be verified clear and empty prior to the commencement of the exercise.

2. Continuous Certification Requirements (CCRs). A ship must satisfy

2	Deter and Counter Terrorist Activities	All duty sections shall demonstrate proficiency in the execution of their Pre-Planned Response IAW their Force Protection (FP)/Inport Security Plan (ISP) (including transitions through FPCONs) to deter and counter the following terrorist activities quarterly: 1. Surveillance a. Land Side b. Water Side c. OPSEC Probe 2. Entry Control Point (ECP) Threat a. Pier penetration b. Shipboard Intruder c. Shipboard Penetration (Forced) 3. Improvised Explosive Device (IED) a. Personnel b. Vehicle c. Suspicious Package 4. Pierside Small Boat Attack 5. Low, Slow Flyer 6. Telephonic Bomb Threat 7. Civil Disturbance (demonstration / protest on the pier) 8. Hostage Situation 9. Seaborne Attack a. Swimmer b. Floating Object 10. Nighttime Small Boat Attack at Anchor

Note: In the interest of safety, simulated weapons (RED/BLUE GUNS) vice shipboard weapons shall be utilized during all training and assessment periods. All Crew Served Weapons (CSW) shall be verified "clear and safe" with no ammunition on deck, prior to conducting training or assessment.

Figure 4. SURFORTRAMAN Tab C – ATFP requirements for small boat attack (DON 2007)

3. Additional AT/FP Resources

The major document at the disposal of Commanders for force protection guidance is the Antiterrorism Force Protection for Naval Operations Commander's Guide Rev A released July 2003 from the office of the Director of AT/FP (N34) Admiral Eric Olsen. While not an instruction per se, this guide is listed as a "pocket guide that consolidates in a single reference a wide assortment of relevant AT/FP information relating to both afloat and ashore assets (ATFP 2003). The ATFP Guide does little to address training issues but goes into great detail regarding threat levels, appropriate responses, and classifications.

The AT/FP Commander's Guide charges Commanders with providing security for forces and DoD assets as well as providing training and education to personnel charged with that protection. (ATFP 2003) Figure 5 is an illustration of Force Protection Conditions (FPCON) based on threat.

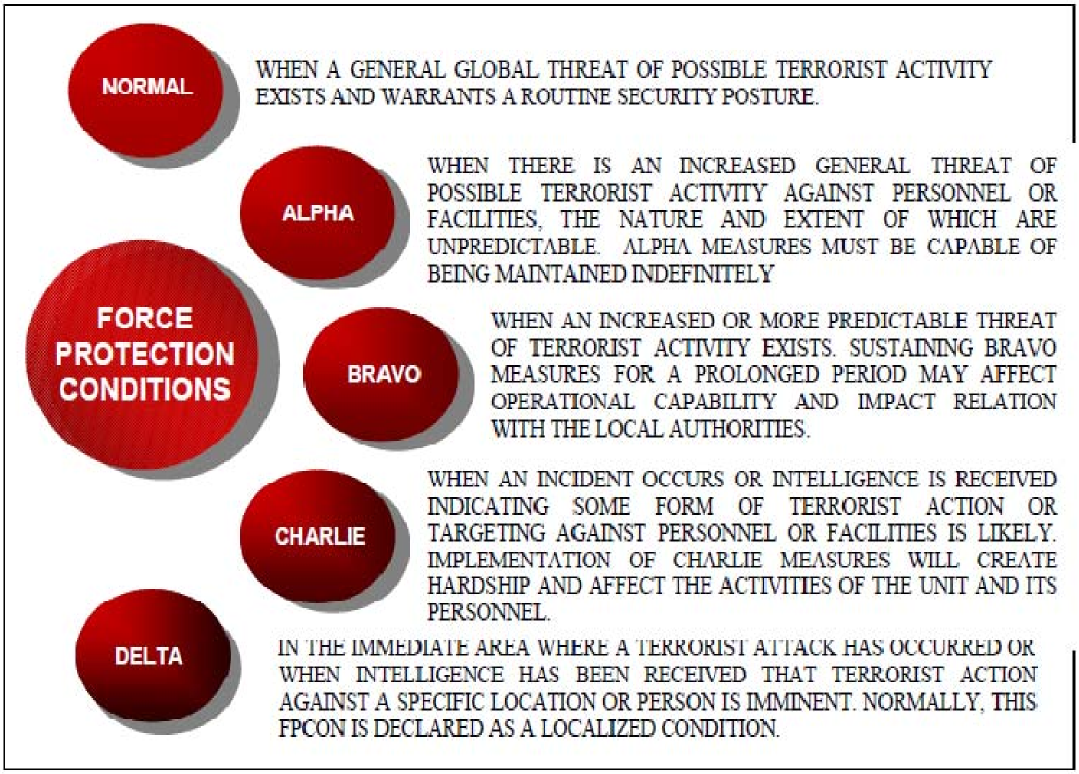

Figure 5. Force Protection Condition (FPCON) summary (ATFP 2003).

C. CREW SERVED WEAPONS QUALIFICATIONS

1. Small Arms Qualification

The Office of the Chief of Naval Operations Instruction (OPNAVINST) 3591.1E issued 20 February 2007 is the current fleet standard for small arms qualifications of U.S. naval personnel. This instruction breaks qualification into four categories. Category I sets the standards for personnel carrying weapons for personal protection. Category II, which is most applicable here, sets the standards for personnel armed for the purpose of

defending DOD property as part of a watch. Category III sets the standards for personnel carrying firearms while operating in support of or directly with expeditionary ground forces. Category IV sets the standards for qualification of personnel operating in a mission specific status such as Explosive Ordinance Disposal (EOD) teams.

OPNAVINST 3591.1E outlines the specific criteria for all personnel assigned to a training role with Crew Served Weapons (CSW). Specifically, any personnel assigned to CSW training positions must complete the USMC CSWI course or other DoD equivalent crew served weapons instructor course with a minimum cycle of two years (Small Arms 2007). This course of instruction differs from the small arms instructor requirements and does not allow personnel to instruct on the use pistols, rifles, or other small arms unless specifically qualified on those weapons as well. This instruction also directs that the student-instructor ratio for CSW shall be no more than 1 to 1. (Small Arms 2007) The category II qualification specifications are outlined in the "qualification criteria for light, medium and heavy machine gun performance evaluation" and are required to be completed by personnel at an interval of no more that 8 months. (Small Arms 2007) Detailed requirements for both the light and heavy machine gun course of fire for qualification can be found in OPNAVINST 3591.1E but both qualifications consist of 6 phases. Figures 6 and 7 are summaries of the requirements for the light and heavy machine gun qualifications respectively.

Phase	Purpose	Distance	Rounds	Starting Condition	Starting Position	Sequence
1	Zero or Establish Hold	400m	20	4	Prone - Bipod Standing-Mounted	20 rounds (3 minutes)
2	Engage Target	400m	20	3	Prone - Bipod Standing-Mounted	20 rounds (15 seconds)
3	Engage Target	400m	20	4	Prone - Bipod Standing-Mounted	20 rounds (20 seconds)
4	Reload	400m	2x10	4	Prone - Bipod Standing-Mounted	One 10 round belt reload one 10 round belt, reload time limit 15 seconds
5	Reload	400m	2x10	3	Prone - Bipod Standing-Mounted	One 10 round belt reload one 10 round belt, reload time limit 15 seconds
6	Barrel Change	N/A	N/A	N/A	Unload, Show Clear	Change Barrel

Figure 6. Summary table for light and medium machine gun qualification. (Small Arms 2007)

Phase	Purpose	Distance	Rounds	Starting Condition	Starting Position	Sequence
1	Zero or Establish Hold	400m	20	4	Prone/Sitting - Tripod Standing-Mounted	20 rounds (3 minutes)
2	Engage Target	400m	20	3	Prone/Sitting - Tripod Standing-Mounted	20 rounds (15 seconds)
3	Engage Target	400m	20	4	Prone/Sitting - Tripod Standing-Mounted	20 rounds (20 seconds)
4	Reload	400m	2x10	4	Prone/Sitting - Tripod Standing-Mounted	One 10 round belt reload one 10 round belt, reload time limit 20 seconds
5	Reload	400m	2x10	3	Prone - Bipod Standing-Mounted	One 10 round belt reload one 10 round belt, reload time limit 20 seconds
6	Barrel Change	N/A	N/A	N/A	Unload, Show Clear	Change Barrel Set/Verify Headspace and Timing

Figure 7. Summary table for heavy machine gun qualification. (Small Arms 2007)

In the event that a 400 meter range is not available or training is occurring at sea, an 8ft by 8ft target often referred to as a "killer tomato" is authorized as an acceptable range substitute (Small Arms 2007). In both cases, time requirements are the sole objective criteria for qualification. Target acquisition and weapons effects on target are graded by the CSW instructor and may be deemed satisfactory so long as the student does not violate any of the range safety parameters dictated in the range safety section of the

instruction. In every case, the target is either stationary (range) or nearly stationary (killer tomato). In addition to the above qualification criteria, drills for Crisis Action Team (CAT) members are delineated in Annex A of the instruction. These drills consist mainly of weapons familiarization exercises although they do cover some of the more tactical aspects of watch standing such as scan patterns for target acquisition.

2. Current at Sea Trainers

Current at sea training devices are limited to a handful of approved items. Two of these are the "killer tomato" and the Robo-ski. The killer tomato is an inflatable orange cube that is deployed from the flight deck or missile deck of a destroyer. Once deployed the ship steams away from the float until it reaches an approximate range of 400 yards. Once that range is reached, the ship comes to all stop and CSW operators are allowed to complete range qualifications in accordance with the standards set forth in OPNAVINST 3591.1E. Not only does a killer tomato bear no resemblance to almost any other object that would normally be seen at sea, but its nearly stationary position does little to nothing to train CSW personnel to be able to engage inbound threat craft. Adequate as it may be for basic weapon proficiency and familiarization training a more suitable training system must be implemented in the fleet for FIAC and swarm defense training.

Figure 8. A "killer tomato" deployed at sea for CSW training.

The Navy has attempted to bridge the training gap by investing in multiple systems such as the Robo-ski jet ski, Sea Fox Unmanned Surface Vessel (USV), and modified Rigid Hull Inflatable Boats (RHIBS) with mixed results. Robo-ski is an

unmanned modified jet ski that may operate alone or in groups. Unfortunately, due to price and availability, these USVs are not currently directly engaged. Instead, towed drones are fired upon and due to the constraints of not hitting the USV, realistic threat profiles cannot be achieved.

3. The Missing Piece

In none of the aforementioned guides or instructions is there a concrete method for evaluating crew served personnel effectiveness against threat craft. There are many reasons for this omission. Chief among them is the inherent complexity of evaluating crews against actual targets. The only current measure of effectiveness would involve using actual ammunition on representative threat craft operating in realistic ways. Clearly this would require a phenomenal allocation of funds to evaluate the numerous AT/FP crews in the multiple fleets. Additionally, a method for steering these vessels would be required. Finally, there are environmental concerns when conducting such an exercise. Firing live ammunition into actual craft would result in the spillage of gallons of fuel and oil for every evolution.

As it stands, the requirement for proficiency for a light machine gunner, heavy machine gunner, or CSW operator is a meager 100 rounds of live ammo fired once every 8 months against stationary targets. The only criteria for satisfactory certification are a time constraint for reloading and the proctor's opinion of the operator's performance. This is insufficient preparation to counter the emerging threat of FIAC in the heavily trafficked littorals in which we frequently operate.

A press release written by Mass Communication Specialist 2nd Class Mark Logico dated June 6, 2007 and released by Commander, U.S. Naval Forces Central Command/Commander, U.S. 5th Fleet Public Affairs Office shows the Navy's attempts to close this training gap with existing technology. The full press release is available at 5th Fleet's webpage (http://www.cusnc.navy.mil/articles/2007/128.html). The Stennis battle group chose to train for FIAC attacks during a straits transit in order to evaluate and increase FP capabilities. Participating in the exercise were USS John C. Stennis (CVN 74), USS Bonhomme Richard (LHD 6), USS Antietam (CG 54), USS O'Kane

(DDG 77), USS Denver (LPD 9) and USS Rushmore (LSD 47). The Stennis used Landing Craft Air Cushioned (LCAC)s as mock FIAC vessels that attempted to penetrate and attack the formation as it conducted a straits transit. According to Cmdr. James Rentfrow, USS Stennis' combat direction center officer "The exercise tests the strike group's ability as a whole to defend itself against small boat attacks. What made this exercise unique was that we used LCACs from the Bonhomme Richard Expeditionary Strike Group to simulate the small boats attacking." As engaging and new as this training may have been, it essentially did what all other current training methods do and that is to stress communications vice CSW capabilities to repel or sink threat craft. "The biggest challenge and reason why we practice this is to perfect our communications, as we have a lot of different elements working together to protect the strike group," said Rentfrow.

D. CREW SERVED WEAPONS

The standard weapons employed for self defense on DDGs are the 7.62mm M-60, the Browning .50 caliber machine gun, and the Mark 38 - 25 mm machine gun system. A recent addition to the fleet is the dual .50 cal mount allowing a single gunner to operate two weapons simultaneously as seen in Figure 9. Table 1 contains the parameters for the three main CSWs in operation in the fleet. The standard configuration for an Arleigh Burke DDG is 2 25mm chain guns on the port and starboard amidships, 2 M-60s on the port and starboard bridge wings, and up to 8 .50 caliber weapons arrayed from fore to aft.

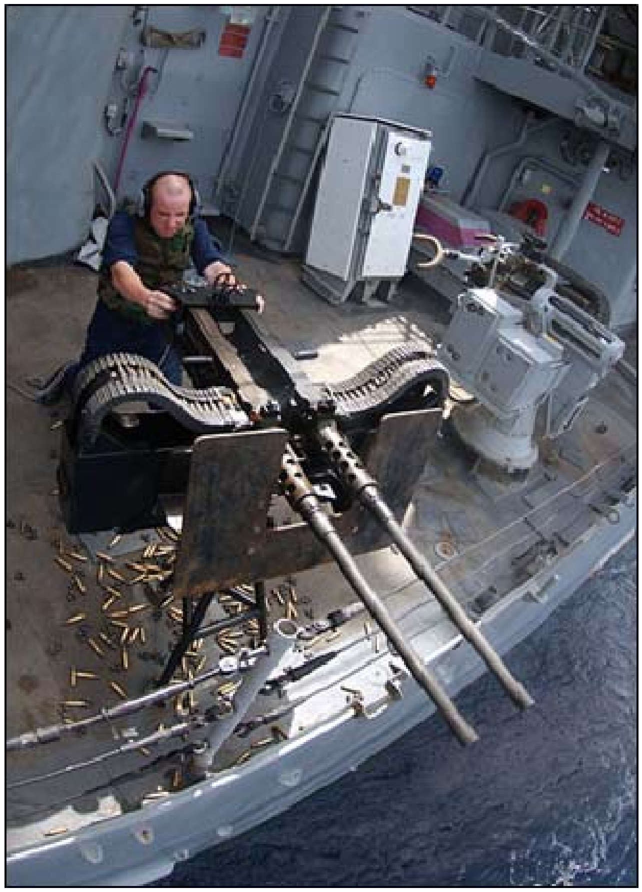

Figure 9. Twin M2HB machine gun (from http://en.wikipedia.org/wiki/Image:Twin_M2HB_machine_gun.jpg)

Name	Number	Round	Rate of Fire	Max range	Max Eff Range
M60	2	7.62mm	550 / Min	3,725 m	1,100 m
M2	4	.50 Cal	450–600 / Min	4.4 Miles	2,000 m
Mk 38	2	25 mm	175 / Min	1 Nm	6,800 m

Table 1. Parameters for common crew served weapons.

E. FUTURE SYSTEMS

1. Augmented Reality

In the context of this thesis, Augmented Reality (AR) will refer to the combination of the real world with some artificiality injected. Simply put, it is in the same vein as the first down line seen superimposed onto the field during National Football League games. AR systems are often used to enhance the information perceived by the viewer. It is this aspect of AR systems that fit the training needs of the Navy very well. The use of an AR system for FP training would allow CSW operators the opportunity to train in more places and in a manner far superior to current methods. One system developed by Lieutenant Nathan Conger at the Naval Postgraduate School could significantly improve waterfront training for FIAC and swarm attacks.

2. Augmented Reality Virtual At Sea Trainer (AR-VAST)

Although still a prototype, the AR-VAST developed by LT. Nate Conger stands to significantly improve watch stander proficiency though the use of real world weapons firing blanks at injected virtual targets (Conger 2008). The current version of AR-VAST uses a monitor for display and only displays a single threat boat. Ideally, the AR-VAST system would be a portable system that could be used with existing gun mounts that would allow CSW personnel to look out onto any harbor and see real world geography with synthetic attack craft. By tracking the position of the CSW, the system would use real world physics to display outbound tracer rounds, damage to FIAC craft, and occlusion due to real world objects such as buoys or other piers. This would allow training to take place in any port, at any time with weapons effects and individual CSW performance being central to the exercise. Instead of a communications drill, of which there are already plenty, AR-VAST would evaluate watch standers ability to do what really matters: fire at and destroy threat craft. Not only would this be a leap forward for real world proficiency but it would allow training to take place in locations where it had previously been impossible while truly testing marksmanship skills all for very little money. Figure 10 depicts a conceptual AR-VAST engagement.

Figure 10. AR-VAST conceptual image showing synthetic tracers and FIAC vessels.

3. General Dynamics XM307

The XM 307 is a next generation CSW contracted by the U.S. Army to replace aging heavy machine guns and grenade launchers. It fires 25mm airburst projectiles up to 2000 yards at a rate of 250 rounds per minute (GD 2005). A system such as this could prove extremely effective at stopping small boats at short range as it integrates the rate of fire and range of a machine gun with the stopping power of a grenade launcher. It is meant to be 2 man portable weighing in at 50lbs and can be operated with a mount. The Navy needs to assess whether this weapon would be a good replacement for, or addition to, its current CSW arsenal. The advantage of a low altitude airburst weapon is that it is not designed to punch small holes in strong armor in the manner that current CSWs do. Hitting a small craft with a fragmentation type munition would be far more effective as there are multiple possible neutralization opportunities that are not taken advantage of by

solid rounds. A single airburst over a small craft has the potential of disabling the three major components of a small craft: its driver, its engine, and its overall seaworthiness.

Figure 11. XM307 25mm airburst crew served weapon from General Dynamics.

F. SUMMARY

The U.S. Navy must keep up with emerging threats and technology. The .50 cal, while an excellent weapon in its own right is over 50 years old. The addition of the dual .50 cal mounts to the fleet is a step in the right direction, but it alone is not sufficient. Current training requirements for CSW gunners are a mere 100 rounds every 8 months and even then the targets do not challenge the gunner's ability to track and repeatedly hit a moving target. The force protection drills in use are essentially communications drills rather than tools to measure gunner proficiency. There are many reasons for these training gaps and the Navy must look to modeling and simulation to fill these gaps. Finally, new weapons systems such as the XM307 must be evaluated for suitability of use in the fleet.

III. SIMULATION DEVELOPMENT ENVIRONMENT

> Since 9-11 the mind set is totally different. We need to deploy, we need to live overseas, we need to be engaged. We can't just sit at home and tuck our tails in and hide.
>
> - Rear Adm. James Kelly

A. INTRODUCTION

This chapter covers the modeling and simulation (M&S) tools used to create and run the model for this thesis. Each tool used will be briefly described and its use explained. These include Java, the Netbeans IDE, Simkit, Viskit, X3D, the Savage 3D model archives, the Savage Force Protection Simulation, and Vivaty beta. Additionally, a short description of the background and implementation of Discrete Event Simulation (DES) is included. While this chapter gives the reader a basic understanding of the applications and uses of the various software and techniques, it is by no means intended as a stand alone tutorial.

B. SCENARIO GENERATION TOOLS

1. Java

Java is a free, open source High Level Language (HLL) designed to work on multiple operating systems. Java is an object oriented language where users write source code with a .java extension which a Java compilers then turns that code into a .class file for running on a Java Virtual Machine (Java VM). These .class files are not native to a particular operating system but rather are intermediate code designed specifically to work on a Java VM. Once compiled, Java .class files can be run using a Java Runtime Environment (JRE).

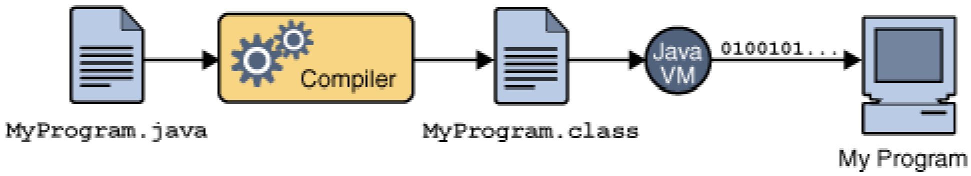

Figure 12. Overview of Java program development (Zakhour 2006)

The Java VM works in concert with a Java Application Programming Interface (API) in order to run Java code on a multitude of hardware platforms. Along with the basic functionality of running Java programs, many APIs share the following minimum features: development tools, user interface toolkits, usually consisting of a Graphics User Interface (GUI) and Java documentation libraries consisting of term definitions and uses (Zakhour 2006).

2. The NetBeans IDE

The NetBeans IDE is a free, open source GUI that allows users to create and run Java files in the form of projects. It requires a Java Development Kit (JDK) and Java Runtime Environment (JRE) to function correctly. Once installed and opened, users are greeted with a welcome splash page and given the option to create a new NetBeans project. The following examples will cover the generation of the basic "Hello World" Java tutorial.

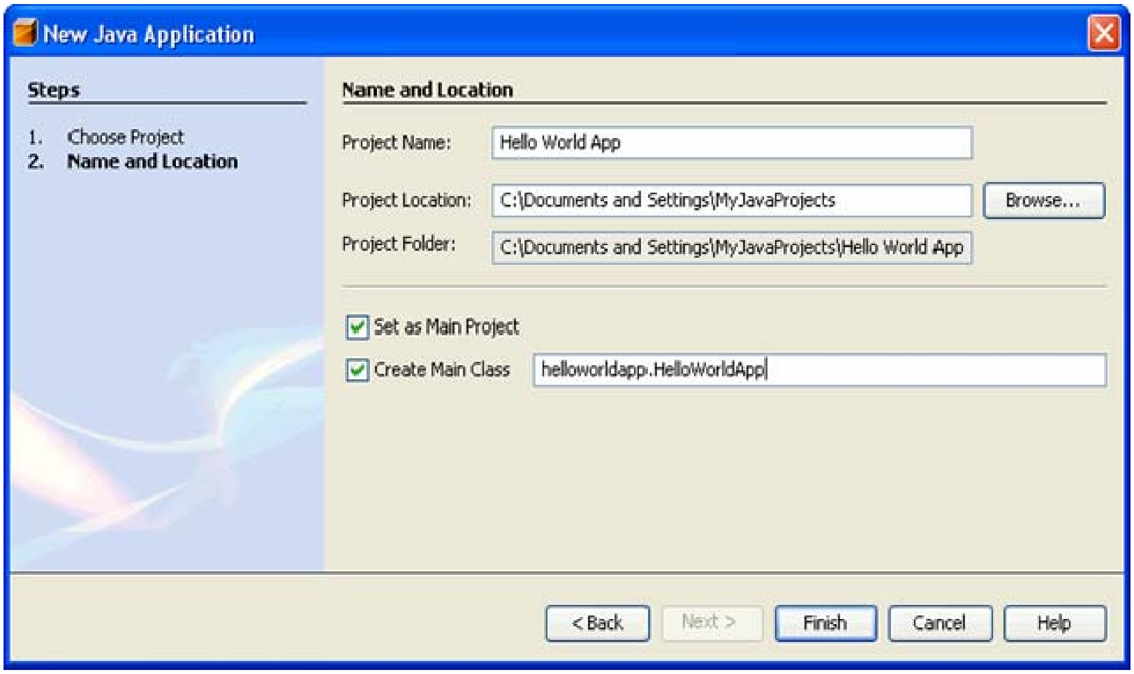

Figure 13. NetBeans IDE generating new "Hello World" Application (Zakhour 2006)

Once a project is created, users establish a source package that will contain all of the source files needed to run that project. The source files are the user authored .java files that are compiled by the IDE in order to form the .class files. Additionally, libraries and test packages in the form of .jar files may be imported into the project in order to test functionality or to expand on standard Java commands. Libraries allow for expanded functionality for specific Java application types. Often, these files will support fully functional programs that run in a Java environment, such as Viskit. Test packages are used to support debugging or as a means of data input to an application. These packages could include background information such as map data. After file creation is completed, applications can be run from the NetBeans console by using the "build" and "run" buttons located in the control panel.

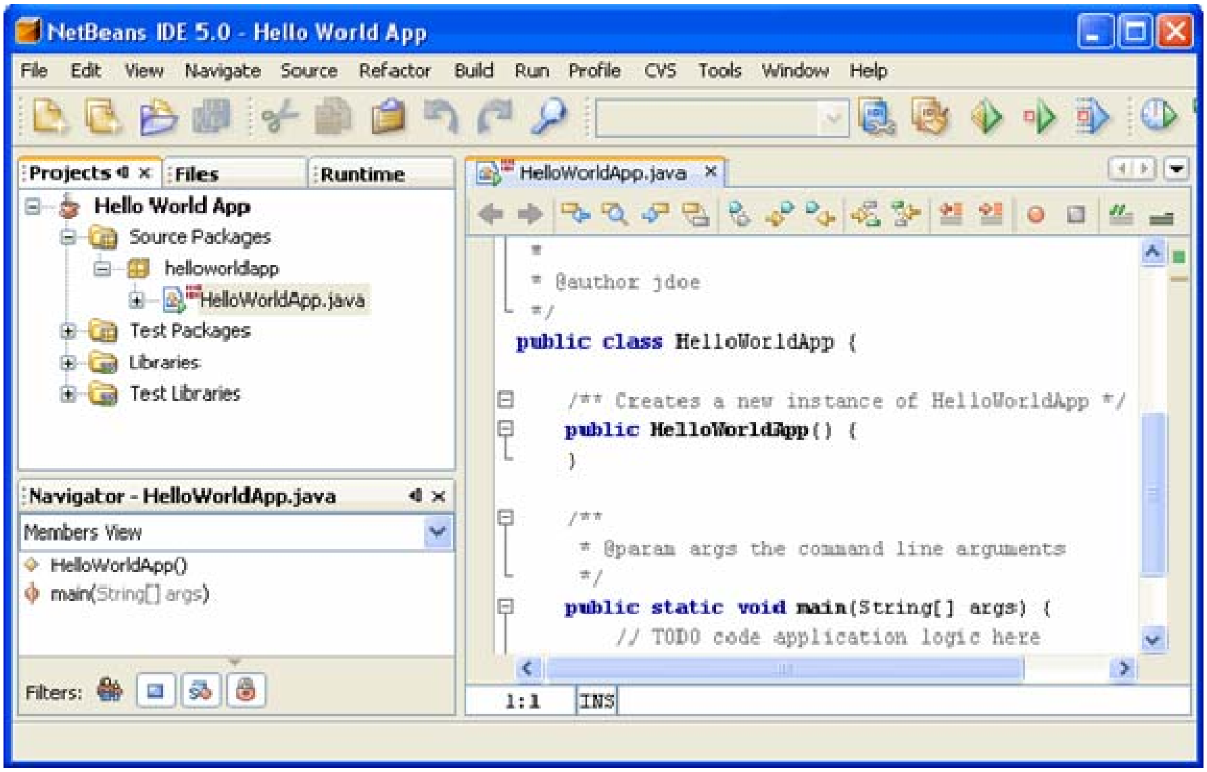

Figure 14. Example source code generation using NetBeans for the "Hello World" application (Zakhour 2006)

3. Discrete Event Simulation

In a traditional time step simulation, an event can only occur at a set interval. The problem with this method is that exactly when something occurred can never be ascertained. Only the time step at which that event was registered is known. Unless an event occurs exactly at a time step, then the report of that event will always be late. Traditionally this is countered by determining what threshold is acceptable for latency of reports. The problem with this approach is that every entity in the simulation that can possibly experience a state change must be evaluated at every time step. Simulations that have a small number of states, or entities that can experience change and simulations that have large time steps, can often overcome these issues. However, if the accuracy of time reporting is very important or the number of entities or states is very large, the computational complexity of these simulations grows exponentially and can become a major problem.

Discrete Event Simulation (DES) is a method of creating and running simulations that do not use time steps as event triggers. DES only update when an event occurs. In other words, a simulation involving the detection of an aircraft will not require its states to be recomputed until the aircraft reaches the sensor threshold. This makes DES computationally lean and fast. It also means that the time reported for a given event is exactly when that event occurred, not the nearest later time step. This causes these simulations to be extremely accurate with respect to time step. DES accomplishes this through the use of event lists. These lists consist of upcoming events that are pre-calculated and are removed once they occur. Figure 15 shows a sample event list for the arrival process application.

Current time	Current event	N	Event list
0	-	-	0: Run
0	Run	0	0:25 Arr
0.25	Arr	1	5.77 Arr
5.77	Arr	2	10.3 Arr
10.3	Arr	3	
...	...	...	...

Figure 15. Graph depicting event list for a DES simulation (Kelton 2008)

One of the simplest examples of a DES is the simple arrival process. The java application Arrival Process is one of the most basic examples of a DES. The application simulates the arrival of entities for use in any number of larger simulations. It could be used for example to simulate and estimate the number of CSW stations needed based on the time taken to engage multiple targets. Note that the arrival times in Figure 16 are constrained only by the mathematic discrepancies inherent in the calculation of floating point numbers rather than based on a time step length. The four columns of the figure represent from left to right: simulation time, the event list, number of arrivals, and events that have already occurred. The event list used here was for a simulation that lasted for 15 seconds yet only had five events including the run event. If this same simulation was run

in a traditional time step simulation using a 1 second time step 16 calculations would have had to be done to accomplish this same output and the closest any event would have been to exactly when that event occurred would have been .33 seconds. If a .5 second time step had been used 31 calculations would have occurred and the closest would have still been .125 seconds off of the correct event time. This clearly demonstrates the superiority in both accuracy and computational complexity in DES.

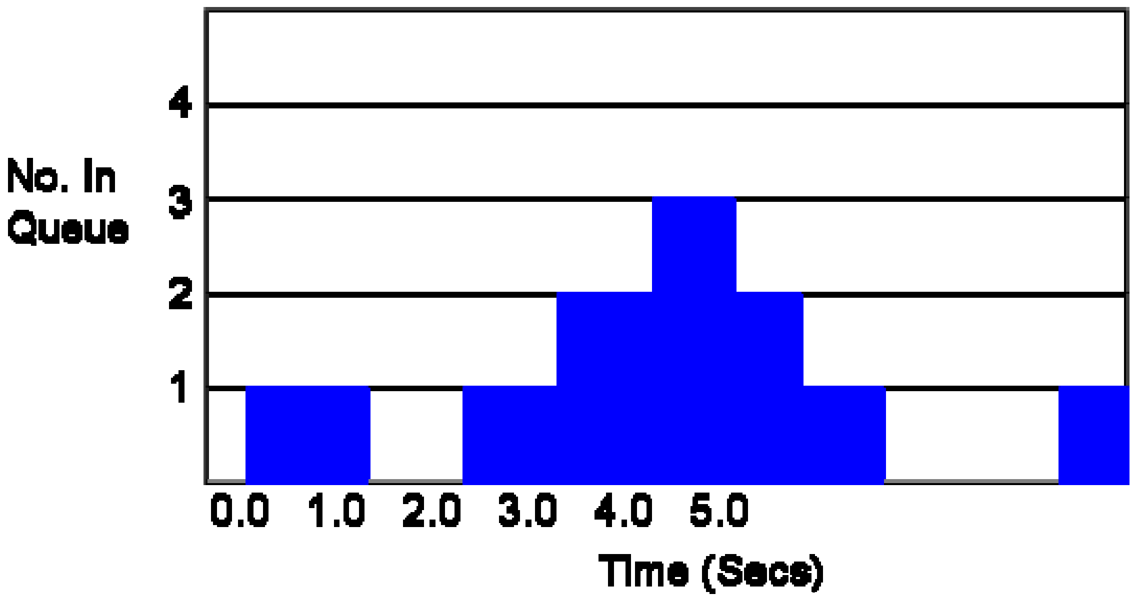

Figure 16. Sample graph depicting arrivals and departures to the arrival process application

4. Event Graphs and Simkit

Simkit is an open source java API designed to implement event graph methodology for DES. The event graph approach to simulation design uses visual representations of code using a specific set of object types and connections (Schruben 1983). Specifically, events are represented as circles connected to one another with lines called scheduling edges. Theses lines represent one event triggering another. Lines may also pass information from one event to another, represented by a square below the line with some parameter contained in it. Finally, a scheduling edge may contain a constraint

for one event to trigger another. These constraints are resented by a "S" or "(" shaped line crossing a line. Events which self trigger have lines arcing out and returning to the same event as shown in Figure 16. Just as the lines previously mentioned, these self-triggering lines may contain constraints or information. The "t_A" shown in Figure 17 on both of the scheduling edges are the delay times for the events to trigger again. These can be set to any number of distributions such as exponential or fixed intervals.

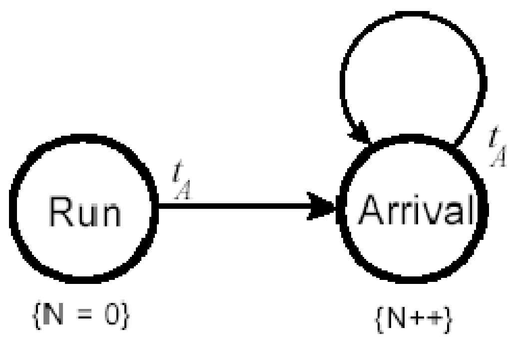

Figure 17. Example event graph depicting the Arrival Process code (Buss 2001)

To use Simkit in Java, begin by navigating a web browser to http://diana.cs.nps.navy.mil/simkit/, and download the latest version of the software (1.3.7 as of 08 Sept 08). Once the software is downloaded, the Simkit .jar files need to be added to the NetBeans project space or whichever IDE project space is being used.

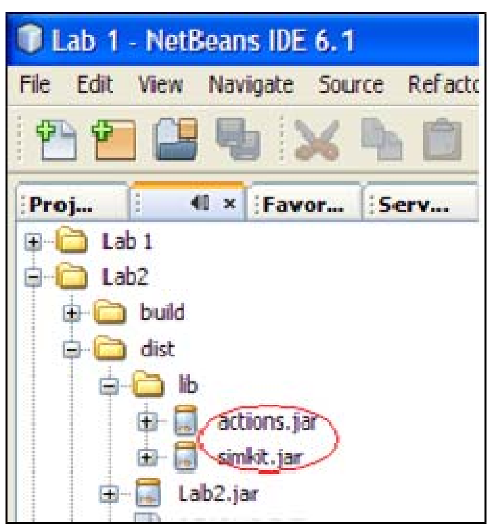

Figure 18. Location of Simkit actions.jar and simkit.jar files in NetBeans IDE

Once installed, the Simkit .jar files will allow Simkit code to be accessed and run using your IDE. The specific items contained in these files are the function calls and libraries used by Simkit. Example code using Simkit and the NetBeans API can be found in Appendix A.

The beauty of using Simkit, and the event graph approach to simulation creation, is that it allows complex processes to be broken down into events, state variables, and parameters. Events are elements that have set times, cause state changes, and are controlled by parameters. State variables are pieces of information that may change over time as a result of events being triggered. Parameters are constants such as delays or the number of items in a simulation such as servers. Using these three building blocks, extremely complicated relationships can be built, piece by piece, in an easily understandable diagram. Unlike raw code, anyone familiar with event diagrams can look at someone else's work and quickly understand the meaning and workings of a simulation design. In this sense, non-code savvy individuals can construct event graphs that can be turned over to coders, who can convert the intent of the event graph into raw code. An example of this is seen in Figure 19 showing a process with two types of service. Viskit will convert event graphs into Java source code automatically.

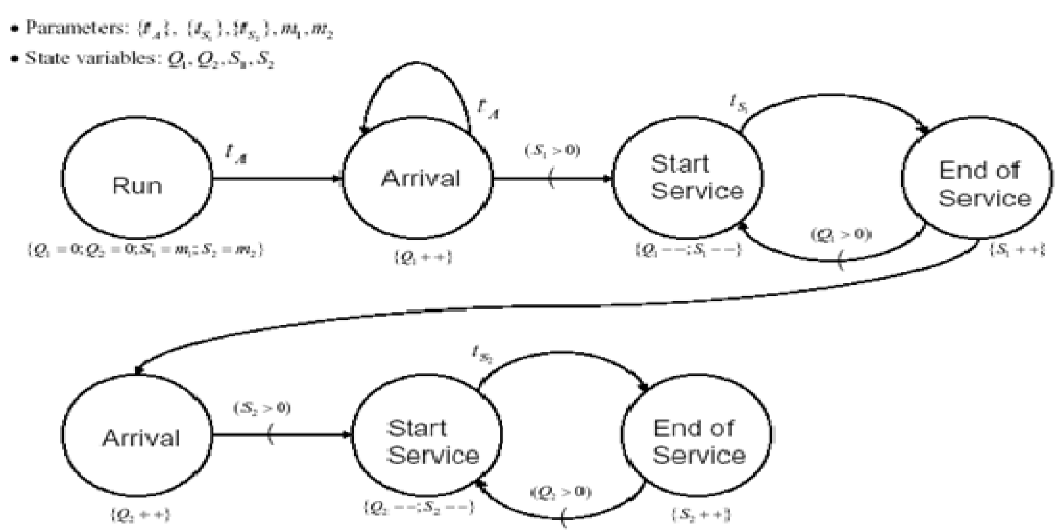

Figure 19. Simkit event graph depicting two types of service (Kelton 2008)

5. Diskit

Diskit expands on Simkit functionality by modeling situations in three dimensions. This functionality allows for more detailed sensor-detection simulations and also for the transfer of data from simulation to simulation via the Distributed Interactive Simulation (DIS) standard. The DIS standard was adopted by the Institute of Electrical and Electronics Engineers (IEEE) in 1995 in order to "define an infrastructure for linking simulations of various types at multiple locations to create realistic, complex, virtual worlds for the simulation of highly interactive activities" (IEEE 1995). The adaptation of Simkit to be DIS compliant was significant as it allowed Simkit to be used either directly or indirectly with all future DIS compliant systems. Figure 20 shows how the DIS standard applies across the 7-layer network architecture model.

Layer	Name	Example of content
7	Application	Kind of data exchanged (position, orientation...). Dead reckoning rules. Rules on determining hit or miss and damage.
6	Presentation	Format of PDUs and their interpretation. Alternative presentation formats such as Protocol Independent Compression Algorithm (PICA). PDUs for field instrumentation, etc.
5	Session	Rules for when PDUs should be issued and which class of communication should be used. Also includes Transmission Control Protocol (TCP) connection establishment for reliable unicast service.
4	Transport	Addressing from end user to end user. Assuring communications reliability, if required.
3	Network	Addressing information from host to host.
2	Link	Framing of information on a physical link. Flags, zero bit insertion. Conflict resolution.
1	Physical	Wire, optical fiber, radio transmission. Voltage levels, impedance values, clock rates.

Figure 20. IEEE DIS requirements (IEEE 1995)

6. Viskit

Viskit is a Java API for the construction of Simkit projects in a visual format. This is useful as it removes the restriction on end users to be proficient in java. So long as the user has an understanding of event graphs and some familiarity with Simkit, complex event graphs can be generated by the average user. Once event graphs are generated using Viskit, the underlying Java code is automatically generated by the system. The combination of Simkit, Viskit, and Diskit formed the bedrock of the Artificial Intelligence (AI) and background parameters for my simulation. Figure 21 shows an example screen from Viskit showing the interconnections of events within the Antiterrorism / Force Protection (AT/FP) simulation in Savage Studios.

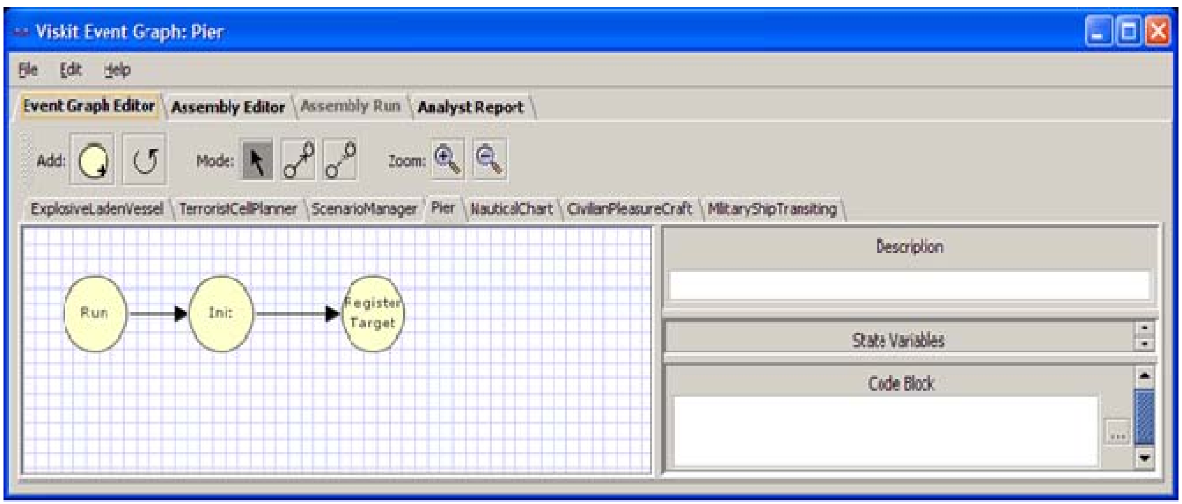

Figure 21. Example event graph for the pier object in Viskit API

7. X3D Edit

Extensible 3D Graphics (X3D) Edit is a well documented, open source scene authoring tool that “uses a scene graph to model the many nodes that make up a virtual environment” (Brutzman 2007). That scene graph is the ISO standard X3D. In this context, a scene graph is a series of interconnected sets of values that represent color, size, location, and many other physical features as well as sensors, sounds, and animation. This is done using a parent-child relationship where nested objects may inherit

aspects of the parent node. The "scene" element contains all of the physical characteristics for a given scene. Below the scene node, transforms set offset locations for shape nodes. The shape nodes contain all of the geometric information for a given object. Figure 22 shows an X3D authored screen shot showing the scene graph, complete with indexed face sets, color values, and location data under the root elements. Figure 23 shows the same .x3d file being displayed in the X3D viewer.

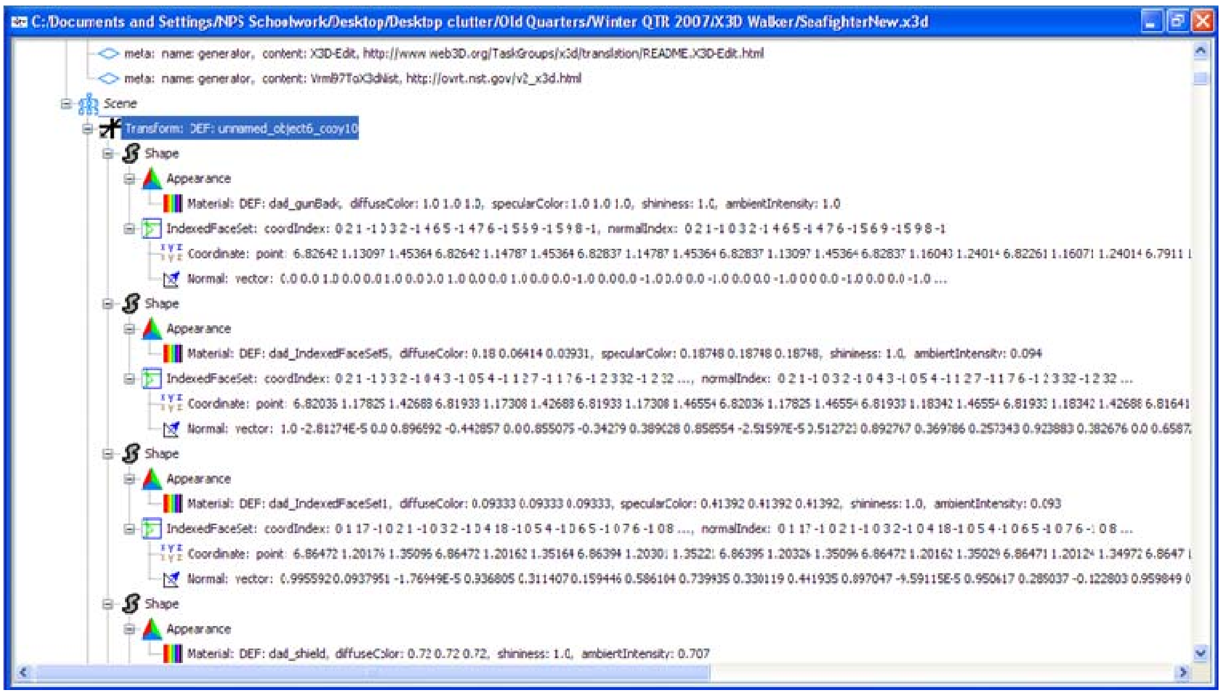

Figure 22. X3D scene showing scene graph.

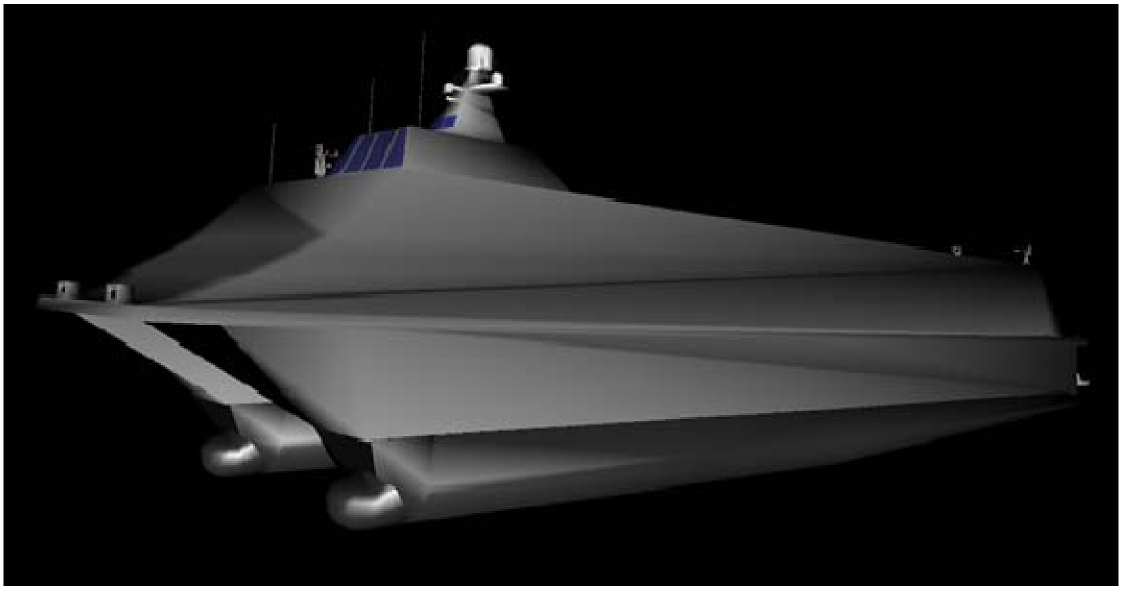

Figure 23. Model using above scene graph viewed in X3D viewer.

8. Savage Force Protection Simulation

The Savage Force Protection Simulation was a project undertaken by LT Pat Sullivan (Sullivan 2006) based on the ground breaking work of LT James Harney (Harney 2003). LT Harney did the background research for the creation of a simulation engine such as ease of use, layout, design, and eventually moved into the functionality of an actual force protection simulation. His work in 2003 resulted in a simulation engine that could be tailored to different ports, ship classes, and behaviors and would give analysis output after scenario runs. Figure 24 is a screen capture of LT Harney's simulation demonstrating the pre-run setup of threat boat characteristics.

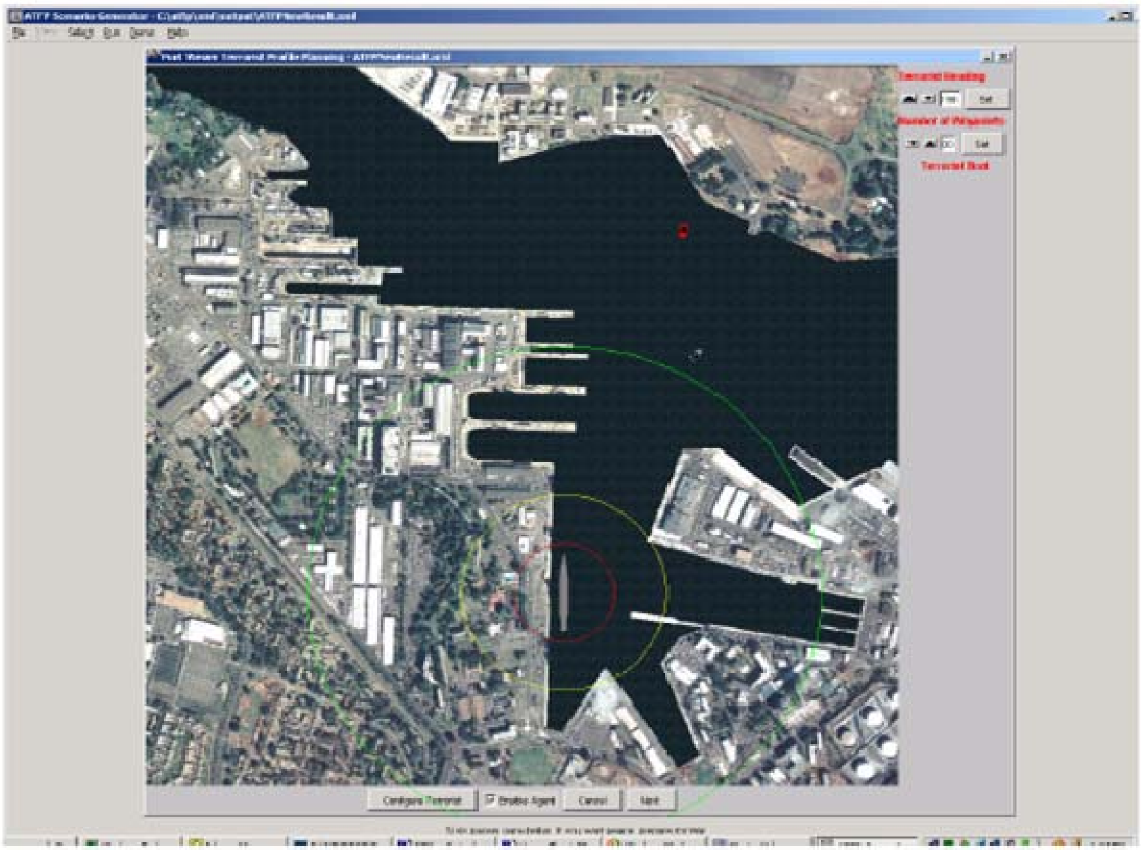

Figure 24. Example of simulation developed by LT Harney. (Harney 2003)

Following LT Harney's work, LT Pat Sullivan added functionality to the simulation in 2006 resulting in the Savage Force Protection Simulation. Sullivan's work centered on giving force protection decision makers the ability to evaluate both tactics and equipment with real world parameters in real world ports. He developed numerous event graphs to control agent behavior to include friendly, neutral, and hostile agents as well as utilities such as map and pier data. Figure 25 is an example of Sullivan's event graph for the friendly patrol boat agent representing the AI for the Rigid Hull Inflatable Boats (RHIB) used in his simulation.

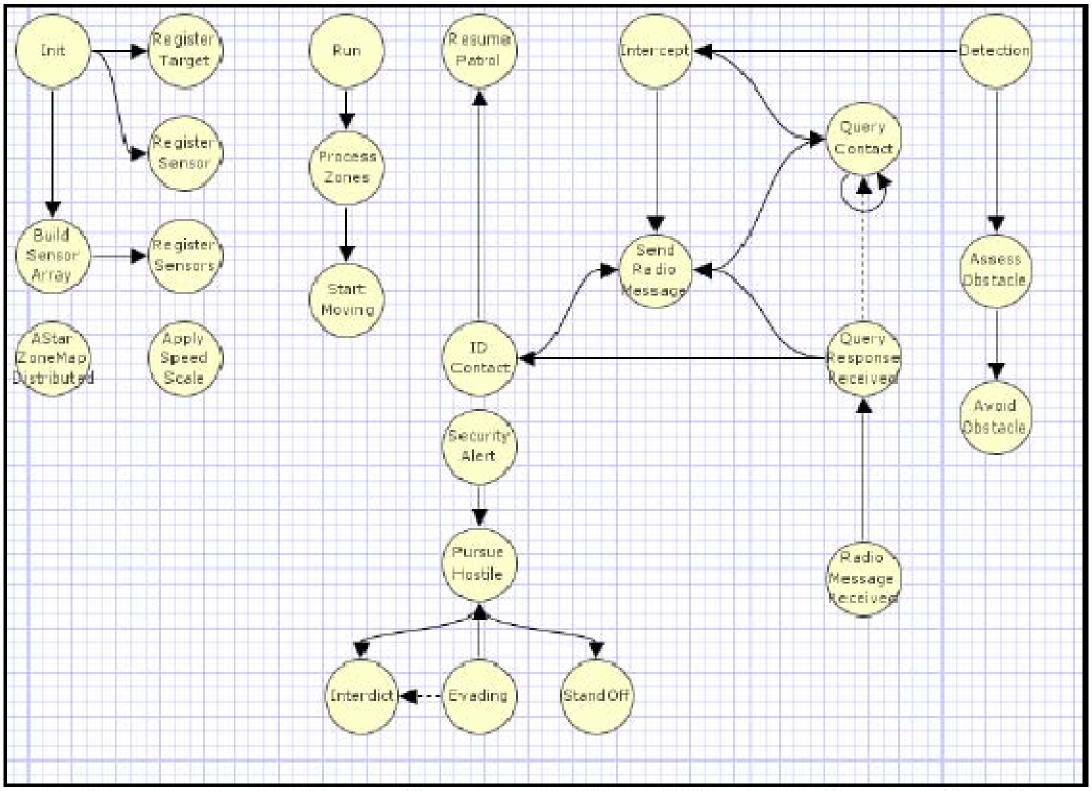

Figure 25. Friendly Patrol Boat event graph (Sullivan 2006)

9. Vivaty Studios (Beta)

Vivaty Studios (Beta) is an open source scene authoring tool available at http://www.vivaty.com/downloads/studio/ with native X3D support. Vivaty acts much like other 3D modeling tools by allowing the user to import a number of open standards extension types and to manipulate a host of variables. Vivaty allows for quick and easy modification of .wrl or .x3d file types and for the construction of multiple layer 3D scenes such as the ones used in this work. Figure 26 shows the display of a model imported from a .x3d file type.

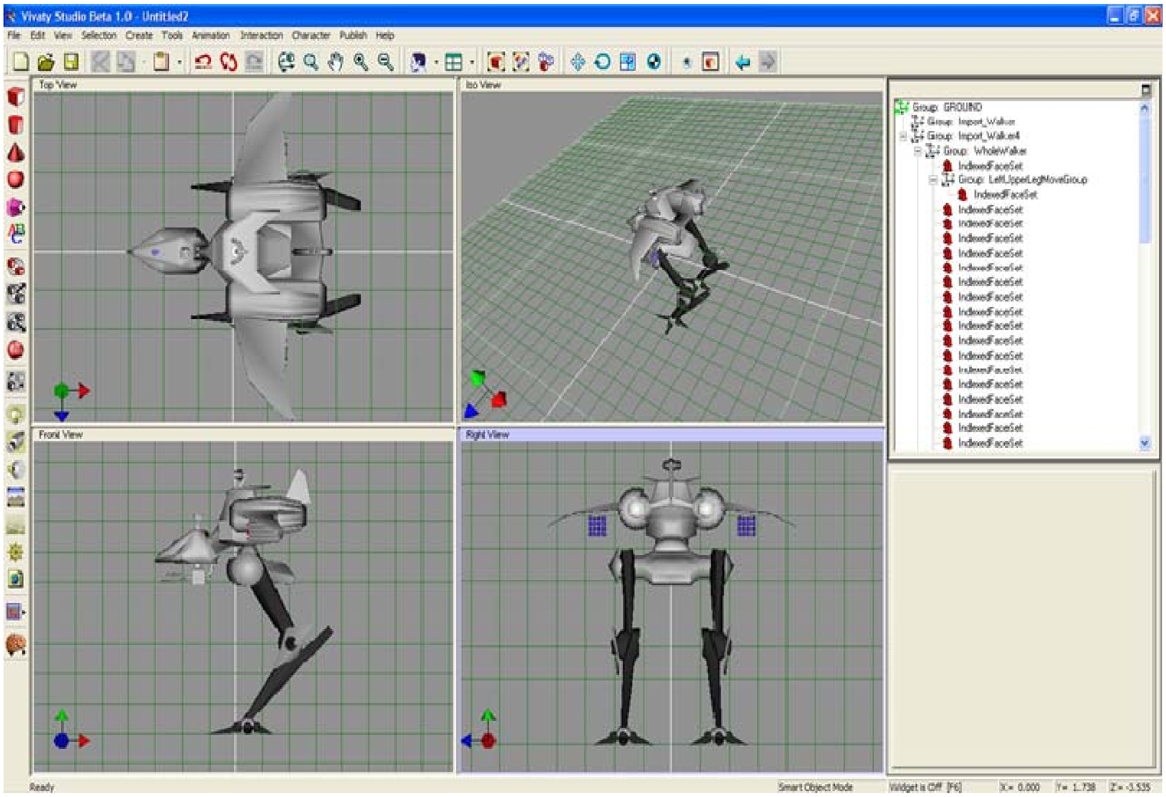

Figure 26. Imported X3D Model displayed in Vivaty application.

C. SUMMARY

Each tool described in this chapter is a building block that allows the scenario to be created. It was intended to demonstrate how complex simulations can be created using a series of easy to use tools. It was this method of starting with the simple, testing it, and implementing it that allowed this work to be done. The short descriptions are not meant to be complete explanations of how to operate any specific piece of software.

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IV. BEHAVIOR MODELING AND SCENARIO SETUP

> Buying the right computer and getting it to work properly is no more complicated than building a nuclear reactor from wristwatch parts in a darkened room using only your teeth.
>
> \- Author Dave Barry

A. INTRODUCTION

This chapter covers the assumptions used for simulation setup as well as a detailed description of how the simulation was designed. Special attention is paid to the interaction of the map data and the agents using that information as well as the parameters used to direct the abilities and actions of the agents.

B. ASSUMPTIONS

1. Environmental Variables

The environmental conditions for this scenario are as follows:

- Visibility – Unlimited (10Nm)
- Sea State – 1 (0-3ft seas)
- Wind - mild (0-10kts)
- Tide – Slack water (0kts current)
- Water depth – As per NOAA charted data for Indian Island

2. Behavior

The behavior for the threat craft was broken into three distinct types. All behaviors were controlled using the Diskit java class "TACTIC." The tactic class contains four distinct behavior modes: Attack, Distraction, Surveillance, and Diversion. All of the behaviors were chosen because they were representative of possible real world scenarios. The first threat behavior is a direct attack. In this mode, threat craft move en

mass from the point of origin directly towards the DDG and attack as soon as they enter the attack range. This was done using the “Attack” profile in Diskit. The second behavior was a diversion by one or more of the threat craft and an attack by others. This was set up using the “Diversion” tactic along with the “Attack” tactic. In this setup, threat craft will harass but not attack the DDG in order to draw attention away from the threat craft conducting the actual attack. The final threat behavior was a distributed attack following threat craft loitering throughout the map and switching tactics to attack when an order was sent from the terrorist cell planner agent. Figures 27 and 28 are the conceptual design for own ship behavior and conceptual design for threat behavior, respectively.

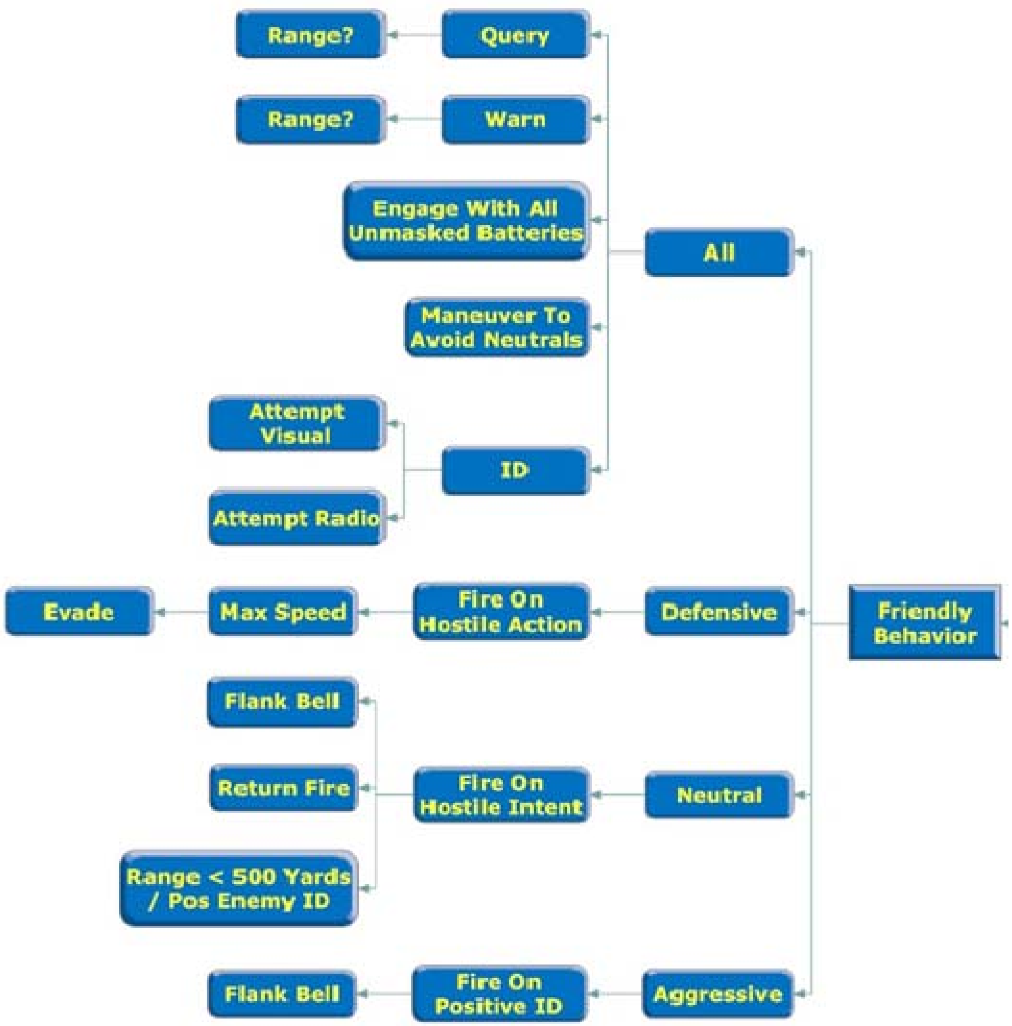

Figure 27. Conceptual design for own ship behavior

Figure 28. Conceptual design for threat behavior

3. Weapons

Weapons effects are not be modeled for the purposes of this simulation. This is done for two reasons. First, weapons effects are not modeled in order to maintain an overall unclassified classification of this work. However, the framework for the inclusion of real world weapons parameters is included allowing for future work to model and analyze these effects under a different classification. The second reason for discarding weapons effects is that this work is more concerned with ranges, threat classification, and the detect to engage timeline.

Chief among the assumptions for weapons exclusions in this simulation is the exclusion of the 5″ main battery of the DDG-51 class ship. This weapon was removed from the options as its range of 12.6 nautical miles creates a potential for rounds to reach sovereign soil of foreign countries in areas where the straits were less than 10 miles across (Jane’s 2007). Additionally, the 5″ gun requires either a fire solution provided by the AEGIS weapons system or a visual solution using the optic scope. In a high contact density environment where threat craft may need to be assessed by actions alone, a robust radar picture does not aid in self defense. Additionally the identification of hostile intent or hostile action will often occur within the minimum firing range of the 5″ gun. For these reasons, it will not be modeled in this simulation.

The second assumption for weapon exclusion is the removal of the Close In Weapons System (CIWS) Block 1B gun mount. While this mount is designed to operate in a surface mode, it is not typically installed on DDG-51 class destroyers. For this reason, it will not be modeled in this simulation.

4. Radar

Both surface search and air search radars were disregarded in the simulation as the surface search radar adds nothing of value to the watch standers in this scenario. The determination of hostile action and/or hostile intent cannot be discerned from a radar picture in this environment as the standard measures for threat assessment such as speed, angle of approach, and location are not sufficient to determine intent when surrounded by

contacts in a strait. While it is possible that watch standers could be alerted by fast moving inbound contacts, it has very little effect on the detect to engage sequence since the approaching vessels may legally operate at fast speeds and move towards the DDG. Additionally, loitering threat craft would offer no information with regard to intent until they launched an attack which could be from a very close range. For these reasons, the only detection sensor available to either the threat craft or to the DDG is a visual sensor with a range of 8000 yards.

C. SIMULATION SETUP

1. Location

The chosen location for the scenario is the area around Indian Island in Washington State. This map was chosen as it has many of the elements critical to analysis of force protection in a channel. The map is large enough to allow for significant time to pass, it contains a chokepoint, and has many options for the starting and ending points for all agents. Figure 29 shows a representative map with red boxes indicating the areas used for the A* search algorithm for path planning and the green boxes outlining the areas of navigable water.

The map is broken up into parent and child relationships for route planning purposes. For each zone represented by a red box in Figure 28, every other zone that was reachable was considered a child. Initially, the map contained some drawbacks in that not all of the zones were connected in both directions. In other words, if zone “A” had zone “B” as a child, then zone “B” should have zone “A” as a child as well. This two way relationship allowed the route planner to determine how vessels could reach their destinations, if at all. However, some of the child-parent relationships were initially one way. This was corrected by editing the Nautical Chart object in the Viskit assembly editor. Within the Nautical Chart, the viskit.AStarZoneGeometry item contained the field for editing children. In Figure 29, all yellow arrows represent correct parent-child

relationships and all red arrows represent one-way connections. All of the one way connections were corrected allowing for complete A* path planning from any point on the map to any other through the correct intermediate zones.

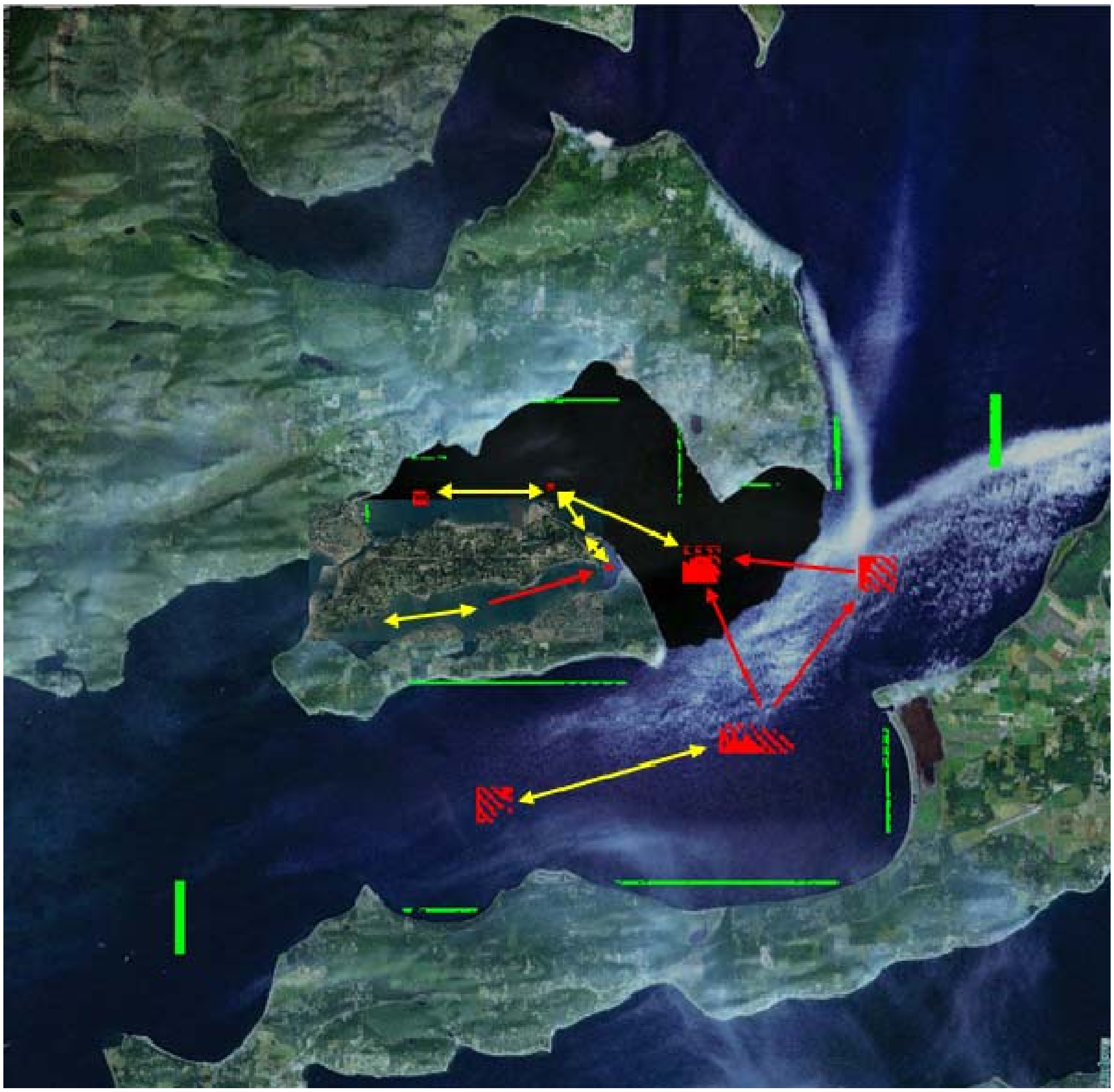

Figure 29. Indian Island map showing starting areas and navigation restrictions

2. Path Planning

All movement is directed via an A* search algorithm. Movement speeds are variables set in the object inspector section of the assembly in Viskit. The parameters here were "close enough" approximations in order to maintain an unclassified overall rating. These variables could easily be set to real world specifications for classified simulations in future work. A 28 knot cruising speed was used for the DDG as a representative speed used during the transit of a foreign strait. The threat attack craft have speeds varying from 0-25 knots and the ferries and sailboats 0-15 knots. Threat small boats will use maximum speed once a target is spotted in all cases. Figure 30 shows the section of Viskit where physical parameters can be modified.

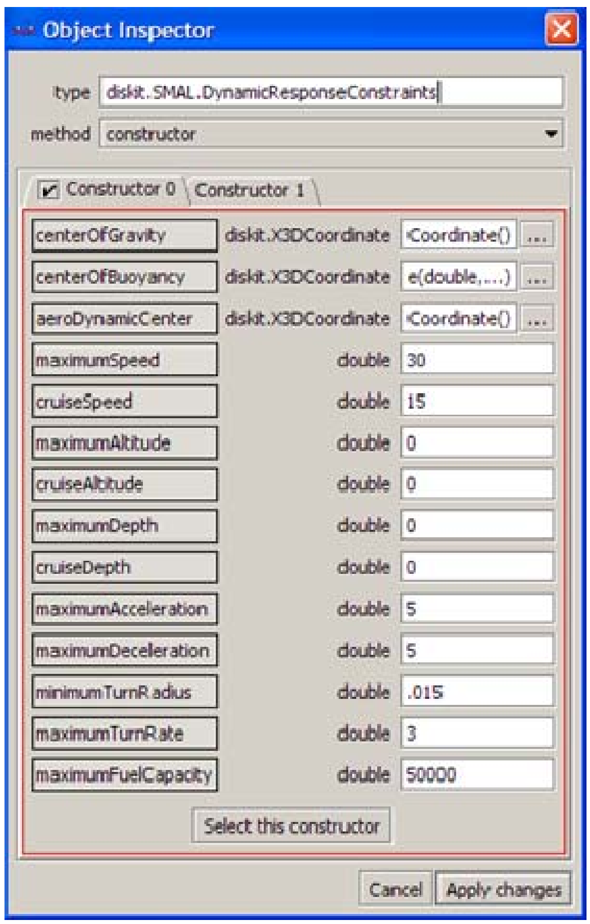

Figure 30. Dynamic physical constraints screen from Viskit showing the movement parameters for the DDG

Threat craft always launch from one of the green boxes considered navigable water in the simulation. One they initialize, the threat craft use the "Closest Zone" method shown in Figure 31 to determine the nearest zone for A* path planning. Once the system compares the vessel's location with the center of all zones, it chooses the nearest one and begins comparing the children in order to generate the optimal path to the destination zone. Once that path is determined, a move order is generated that commences threat craft movement through the scene.

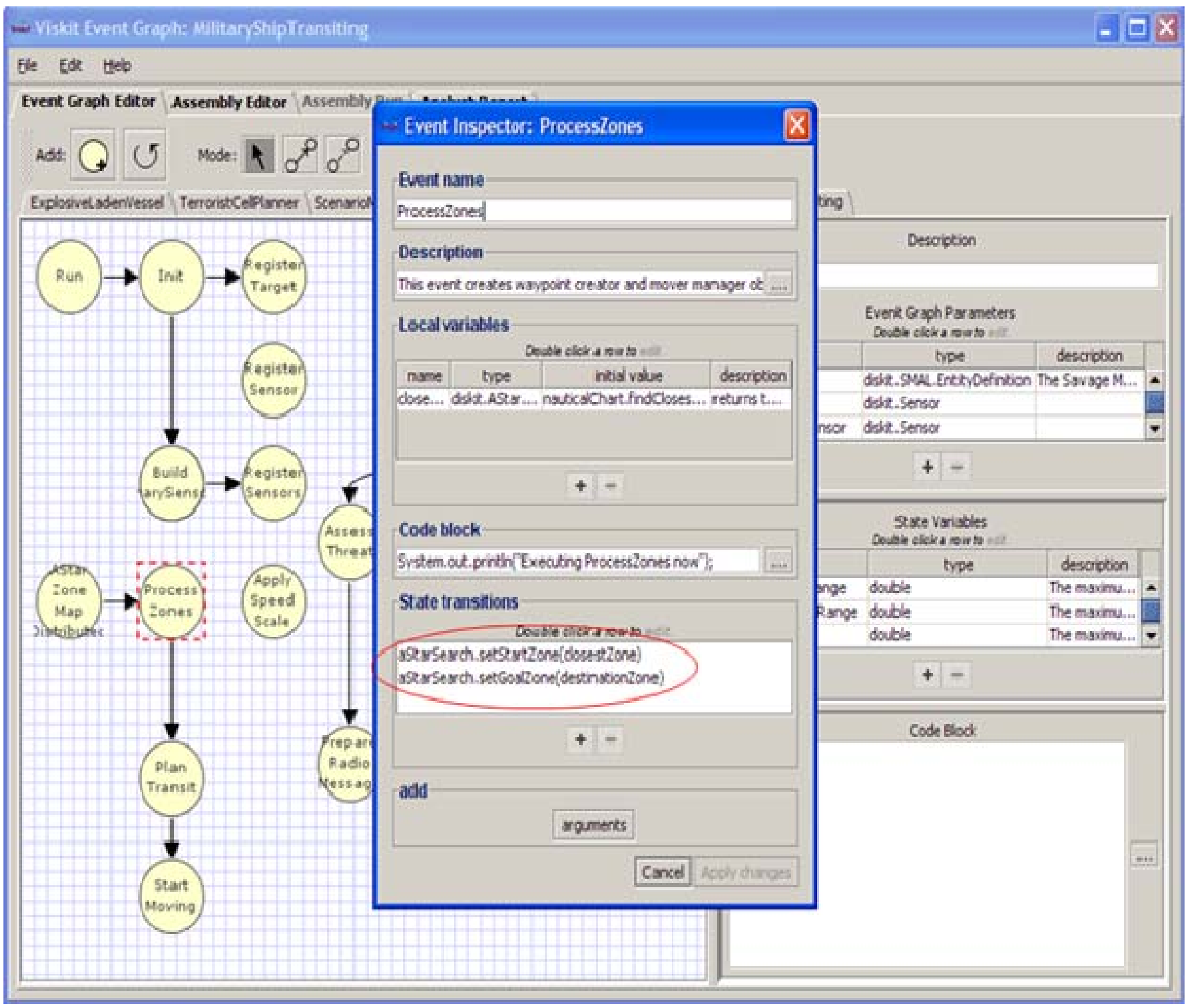

Figure 31. Threat craft event graph showing the zone search state transitions for path planning.

3. Models

All of the models used are located in the Savage 3D Model Archive (https://savage.nps.edu/Savage/). The primary models used were the Arleigh Burke high detail prototype, sail boat under sail, and the speed boat with driver as the threat craft. The DDG prototype was modified using the weapons coverage model and the U.S. Marine avatar as the CWS operator. Figure 32 shows the model as it appeared in the simulation complete with CSW watch standers and weapons arcs of fire. This was accomplished by editing the IndianIslandSwarmDIS.x3d file as show in Figure 33 and adding prototypes to the base model.

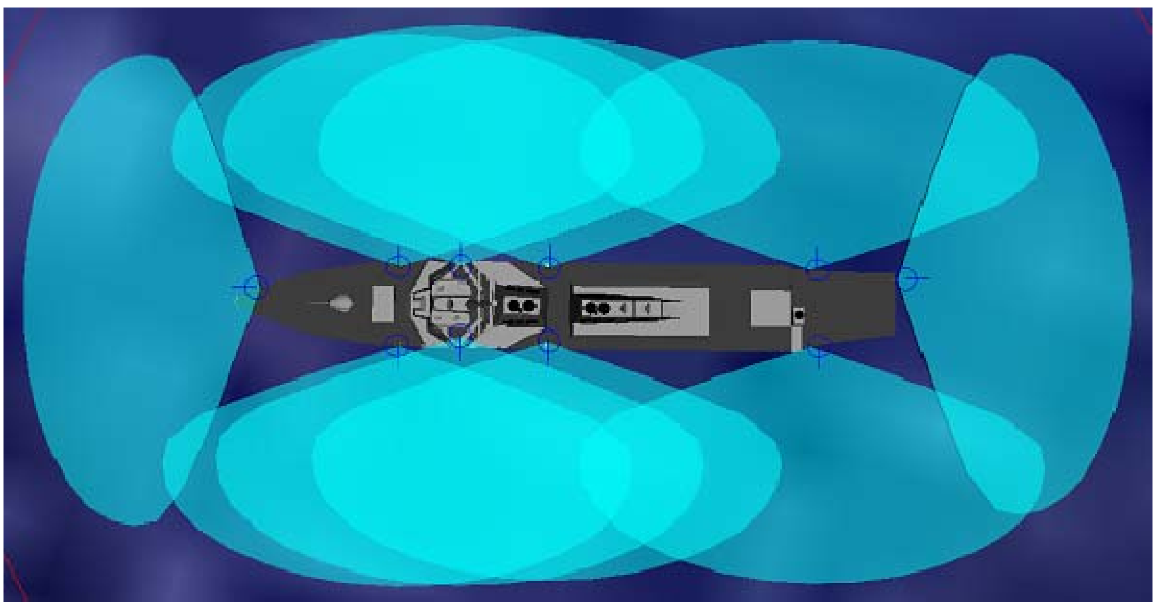

Figure 32. Arleigh Burke high detail prototype with Marine models and weapons coverage.

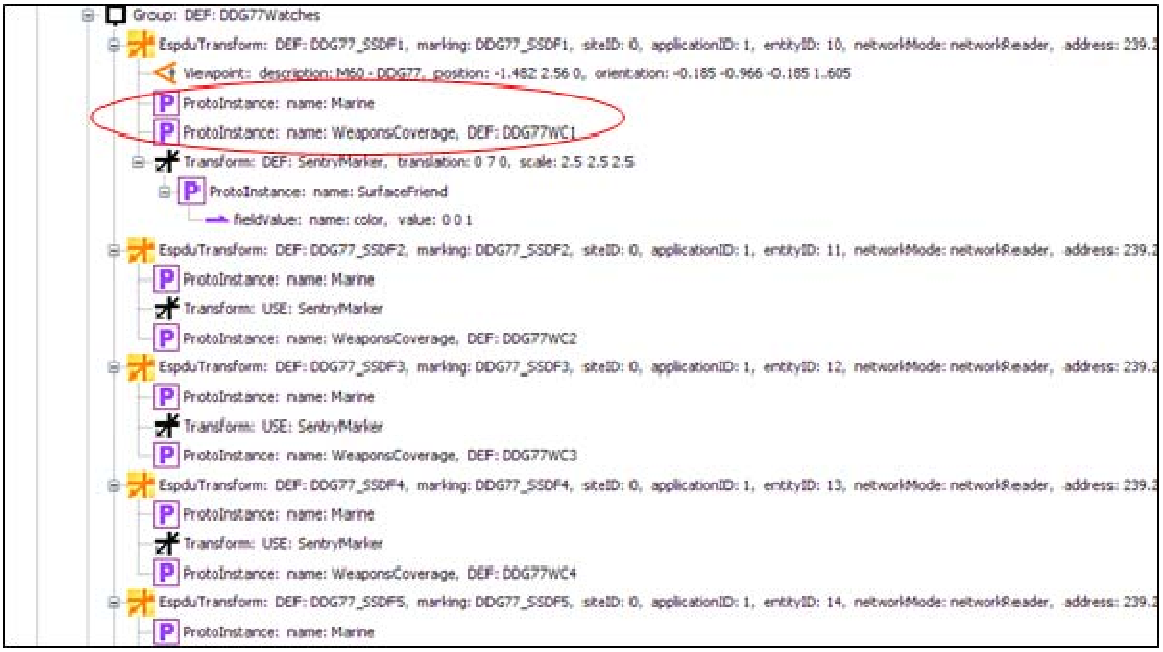

Figure 33. IndianIslandSwarmDIS.x3d file showing the addition of marine watch standers and weapons coverage prototypes.

4. Event Graphs and Assembly Code

The event graphs driving the simulation consist of seven distinct entities. The Nautical Chart event graph contains all of the information regarding the navigable water and zones needed for the A*. Upon instantiation, the Nautical Chart generates all of the AStarZoneGeometry needed by the rest of the simulation for movement and path planning purposes. The applicable agents have a listener event that allows the individual agents to determine how and where to move. The Scenario Manager is essentially the mediator for the entire simulation. It contains the master run and initialization events as well as the parameters for stop time and stop conditions.

The Terrorist Cell Planner event graph is the Command and Control (C2) behind the threat craft and dictates starting positions, ending positions, tactics, and start times. This allows for complex behavior since the planner can order different movers to operate in different ways. In this manner, vessels can loiter, distract, or launch an attack at any time in the simulation. Finally, the cell planner tells the attackers what their target is and where geographically they are allowed to engage that target. The Explosive Laden Vessel

event graph takes in the nautical chart information and uses it to execute the movement orders from the cell planner. Once the operating criteria are dictated the craft become autonomous unless additional or contradictory orders are received. The threat craft use an intercept algorithm which once a target is detected and the solution, if one exists, from that algorithm become the course and speed that the threat craft will use. Threat boats also report attack attempts and results back to the cell planner.

The Civilian Pleasure Craft event graph creates a neutral vessel behavior that can be directed to randomly traverse the map or to move in a repeating path like a ferry. The pleasure craft have only a visual sensor for detection and in this case the range of that sensor was reduced to 200 yards in order to recreate situations where pleasure craft are not following the accepted rules of the road or are not paying attention to other vessels.

The Pier event graph is a holdover from Pat Sullivan's work and while not necessary for this simulation, it was not removed for the benefit of future projects. The pier exists only as a physical barrier to movement, a collision detection object, and as a communications hub if used. The Military Ship Transiting event graph is similar to the explosive laden vessel event graph with some exceptions. The military ship has an event that evaluates a detected contact to attempt to classify the contact as friend, neutral, or threat. Additionally, the military ship has a radio communication event that can be used to send and receive messages or issue queries and warnings. Figure 34 shows all the event graphs used.

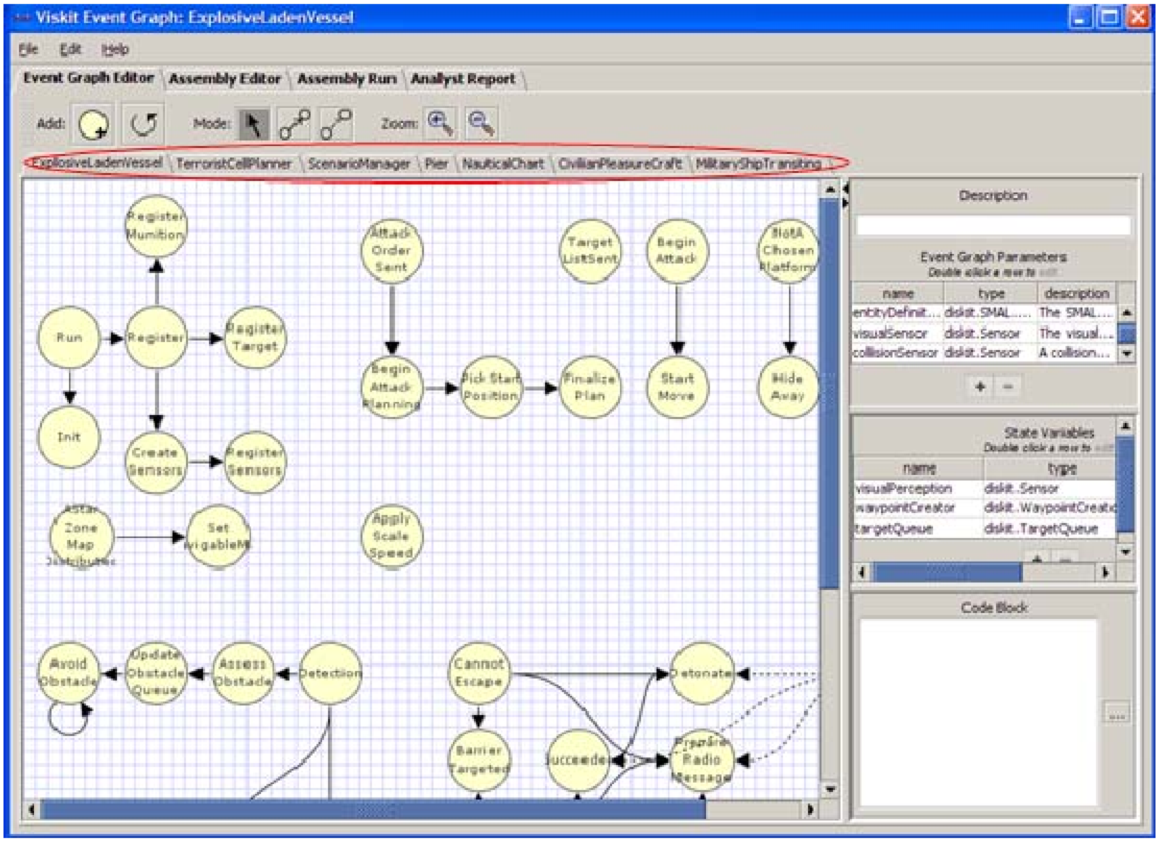

Figure 34. Viskit event graph editor showing all of the event graphs used in the simulation.

The assembly is an XML file that ties all of the event graphs together and delineates the relationships between all of the elements in the scene. All connections are listeners that allow the different event graphs to "hear" and respond appropriately to other event graph triggers. Note that the explosive laden vessels listen to both the planner and the scenario manager. This is because they require both physical and geographical information from the scenario manager as well as tactical and path information from the cell planner. All other movers listen to the scenario manager only and the nautical chart listens to nothing, but contributes all of the physical information to the rest of the assembly. Figure 35 shows the IndianIslandSwarm.xml assembly file.

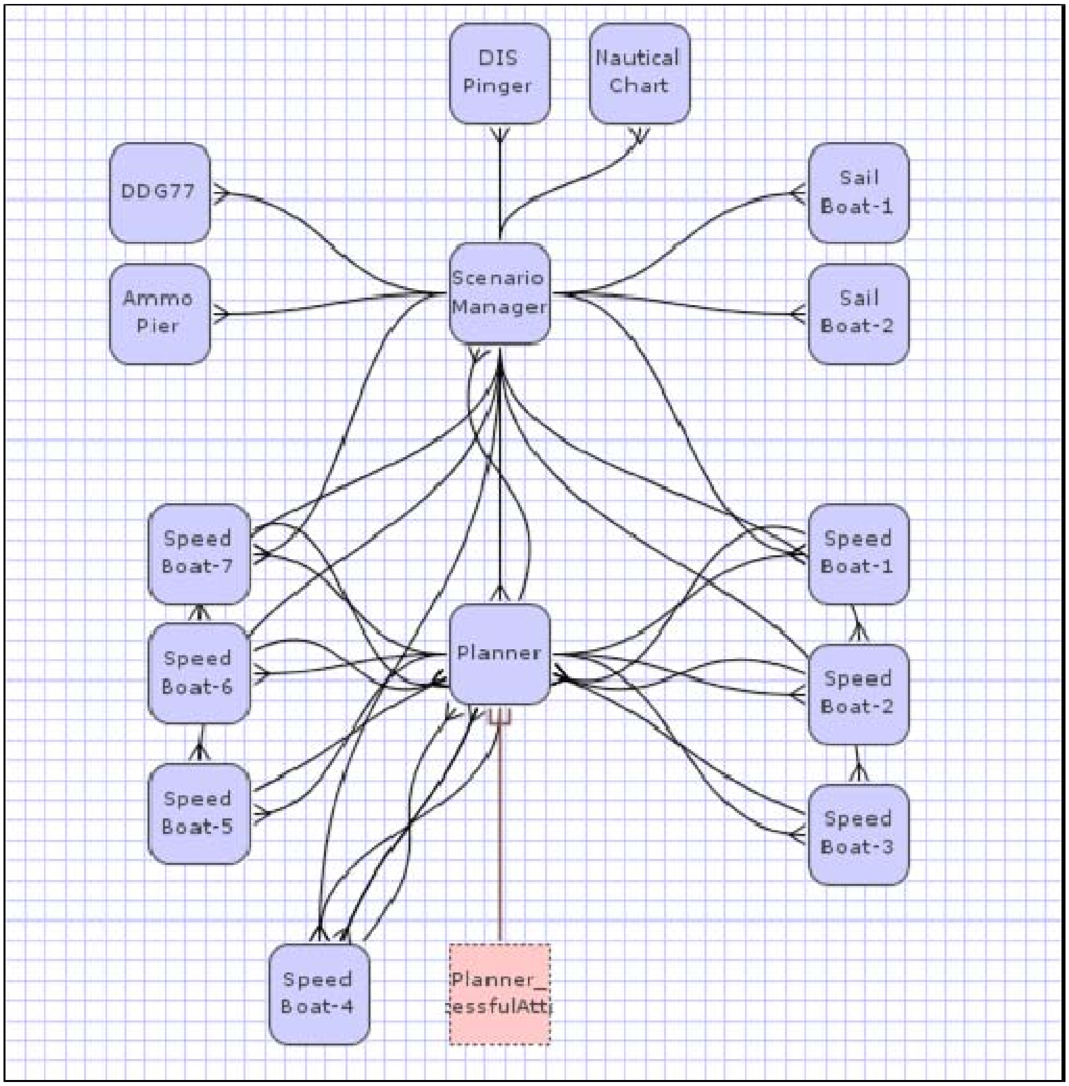

Figure 35. Indian Island swarm assembly file showing interconnections between event graph representations.

5. Scene Setup

Two scenes were created for analysis. In both cases, the DDG begins its transit in the area denoted by the green circle in Figure 36 and begins transiting south. In the first scenario, the threat craft launch from the southern most corner of the map and immediately begin to transit north. This was accomplished by hard coding the starting point of the small boats to correspond to the Mutiny Bay waterway. Neither the small boats nor the DDG have any initial information regarding each other and rely on a visual sensor in order to detect each other. In the second scene, the small boat starting location

is randomized by removing the Mutiny Bay restriction in the “Select Start Area” event in the terrorist cell planner event graph. Figure 37 is a screen capture from the simulation showing the DDG transiting with the terrorists visible on the horizon. Figure 38 shows the terrorists traveling in a loose formation towards the DDG.

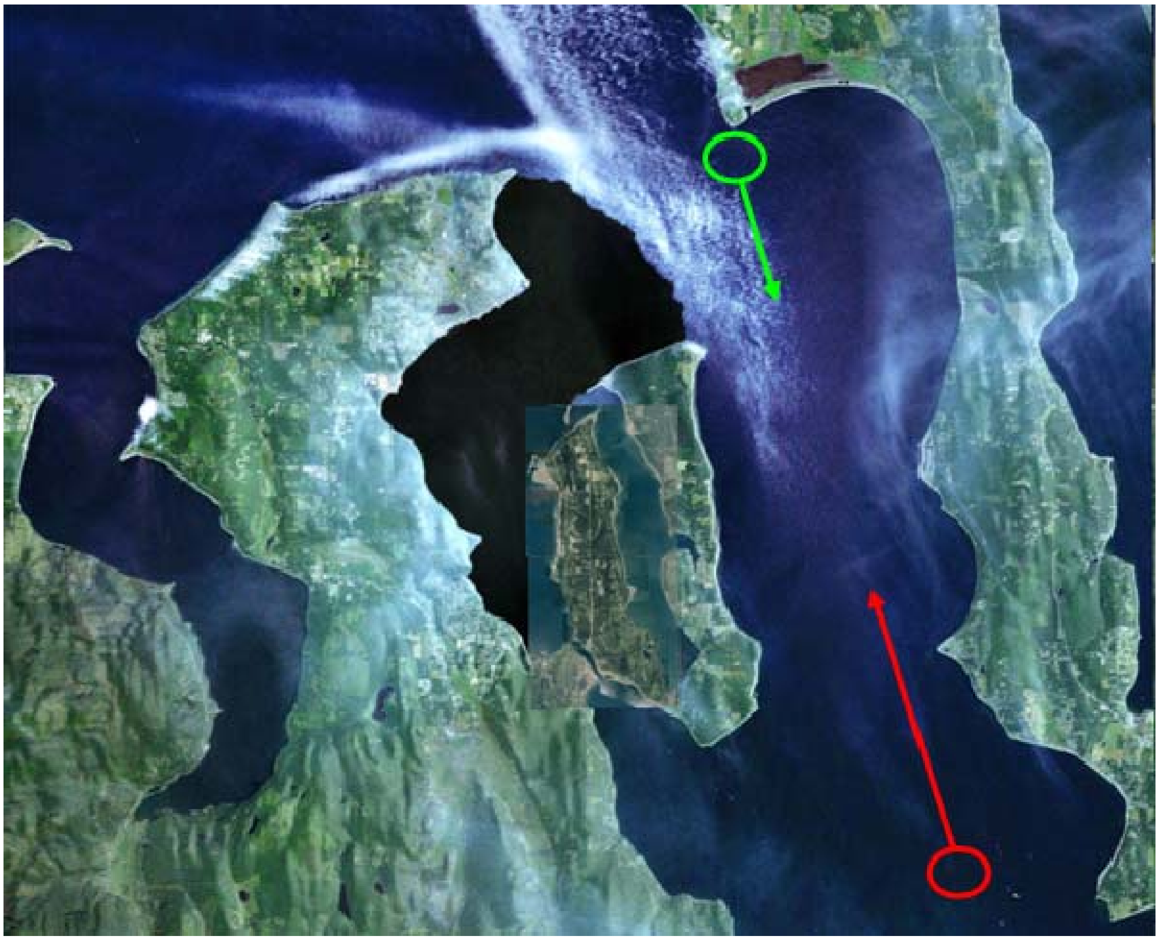

Figure 36. Indian Island map showing the starting locations of the DDG (green) and threat craft (red)

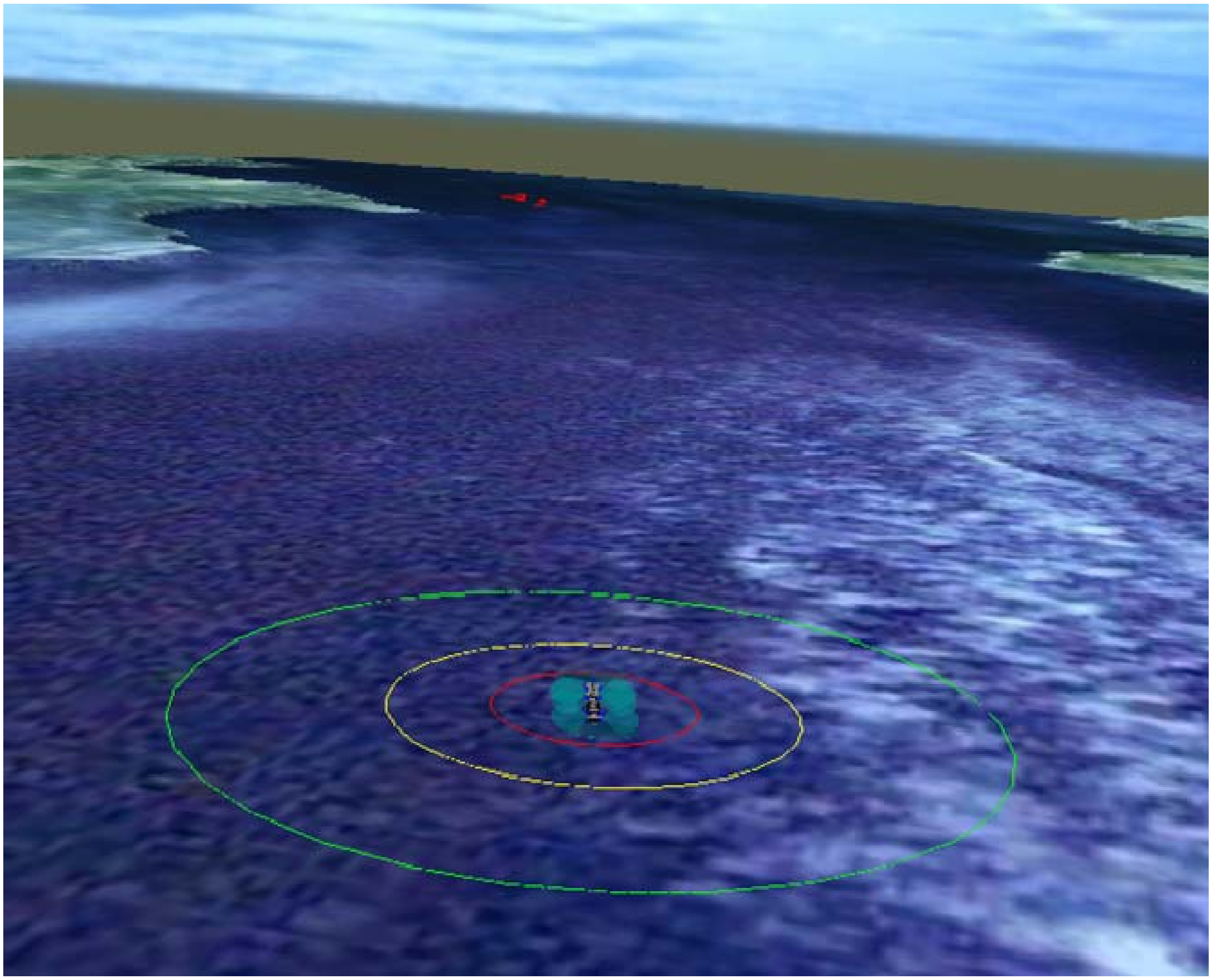

Figure 37. Screen capture showing DDG traversing towards threat craft. Various engagement zones are depicted by the different color range rings.

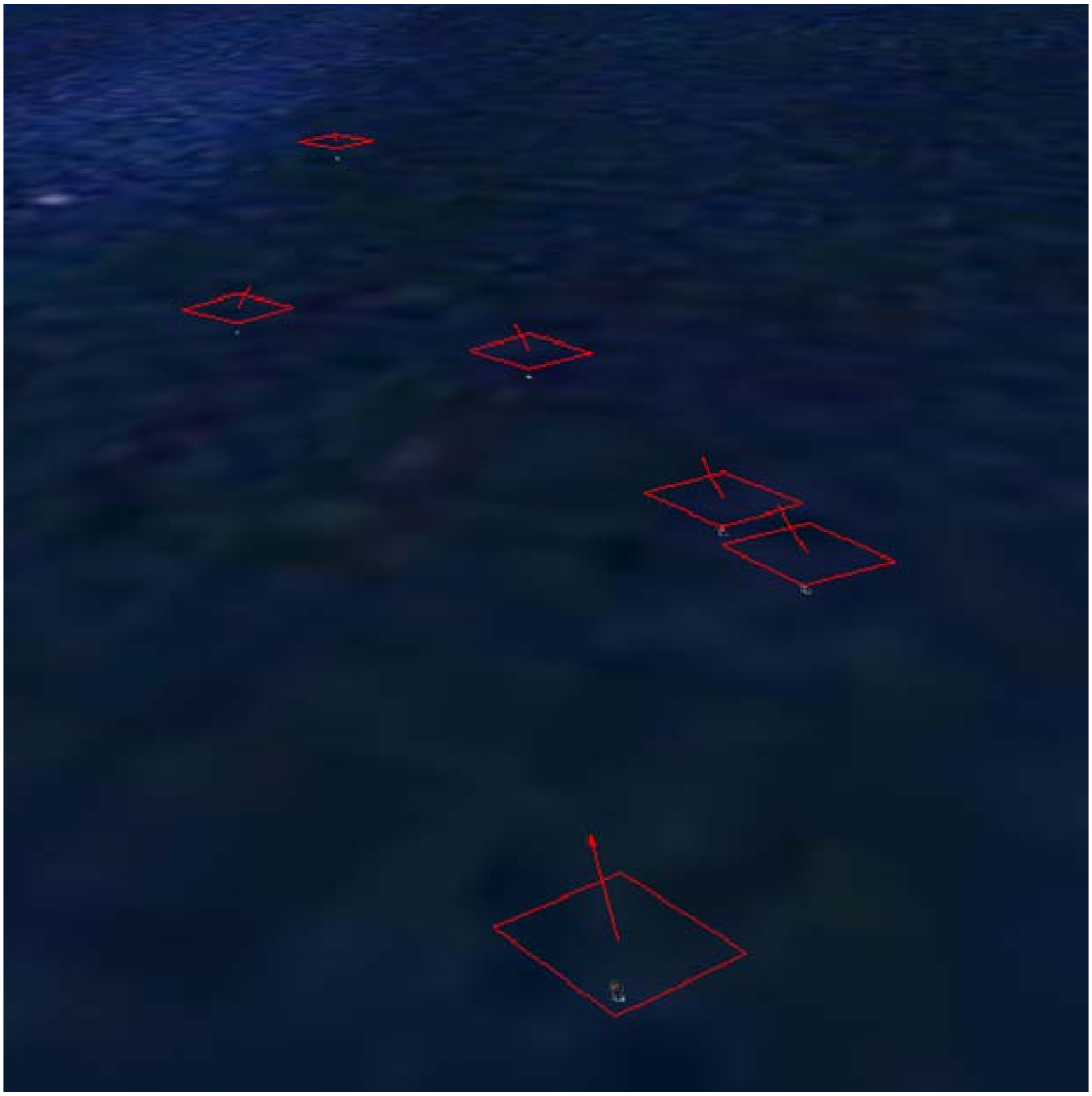

Figure 38. Screen capture showing threat craft moving towards DDG. Note the use of unit symbology.

D. SUMMARY

The combination of event graphs used in the simulation allowed for a robust model capable of analyzing a wide range of data. The addition of real world parameters, weapons capabilities, and tactics will enable decision makers to evaluate new tactics, weapons, sensors, and ROE in a classified simulation. This model can be adapted easily to evaluate formation steaming, path planning in a dense environment, or any number of other situations.

V. ANALYSIS AND CONCLUSIONS

A. INTRODUCTION

This chapter covers the outcome of scenario generation, the original intent of my work, and what I was actually able to accomplish. While the background research yielded gaps in training and aged weapons systems designed for use by land forces, the simulation did not reach full capability during the allotted period.

B. SIMULATION ASSESSMENT

1. The Positives

The Savage Force Protection simulation tool is a tailorable, scalable, and realistic simulation authoring application. An extraordinary amount of work has gone into developing the underlying Diskit, Viskit, and Java files as well as the GUI. With training, a competent analyst can create almost any realistic scenario. Using the embedded parameter menus, future sensors, weapons, ships, and tactics can be analyzed. The scenarios can be run in any location for which bathymetric data and digital images are available. Complex AI can be created easily using the menus within the terrorist cell planner and explosive laden vessel event graphs. Ships of any class can be introduced easily into a scene since it uses open source file extensions such as X3D. Modifying models is as easy as editing X3D files to include or remove watch standers, weapons, and graphics while physical parameters can all be modified from within Viskit. In addition to the vast number of models available in the Savage 3D Model Archive and the behaviors already implemented in Viskit, brand new models and behaviors can be developed by making new Viskit event graphs. Tutorials for almost every skill required to author a scene in Savage Studio are available from websites such as Sun Microsystems and NPS. This simulation will continue to evolve and would be greatly beneficial to anyone modeling and analyzing maritime scenarios.

2. The Issues

Due to unidentified bugs, I was unable to run a complete simulation. There appears to be a problem with the A* path finding algorithm. When the DDG was placed in the scene between Admiralty Inlet North and Admiralty Bay it would correctly identify Admiralty Bay as the nearest zone. However, when the DDG traversed to Admiralty Bay it incorrectly identified the children and, instead of continuing on to Admiralty Inlet South, it entered an infinite loop and attempted to reach its current destination over and over again causing the simulation to crash with a result of never reaching the termination point in the run. Figure 39 shows what the Admiralty Bay children should be. Figure 40 shows the path developed by the A* algorithm as displayed in the output window in Viskit.

Figure 39. Nautical chart event graph showing the correct child nodes.

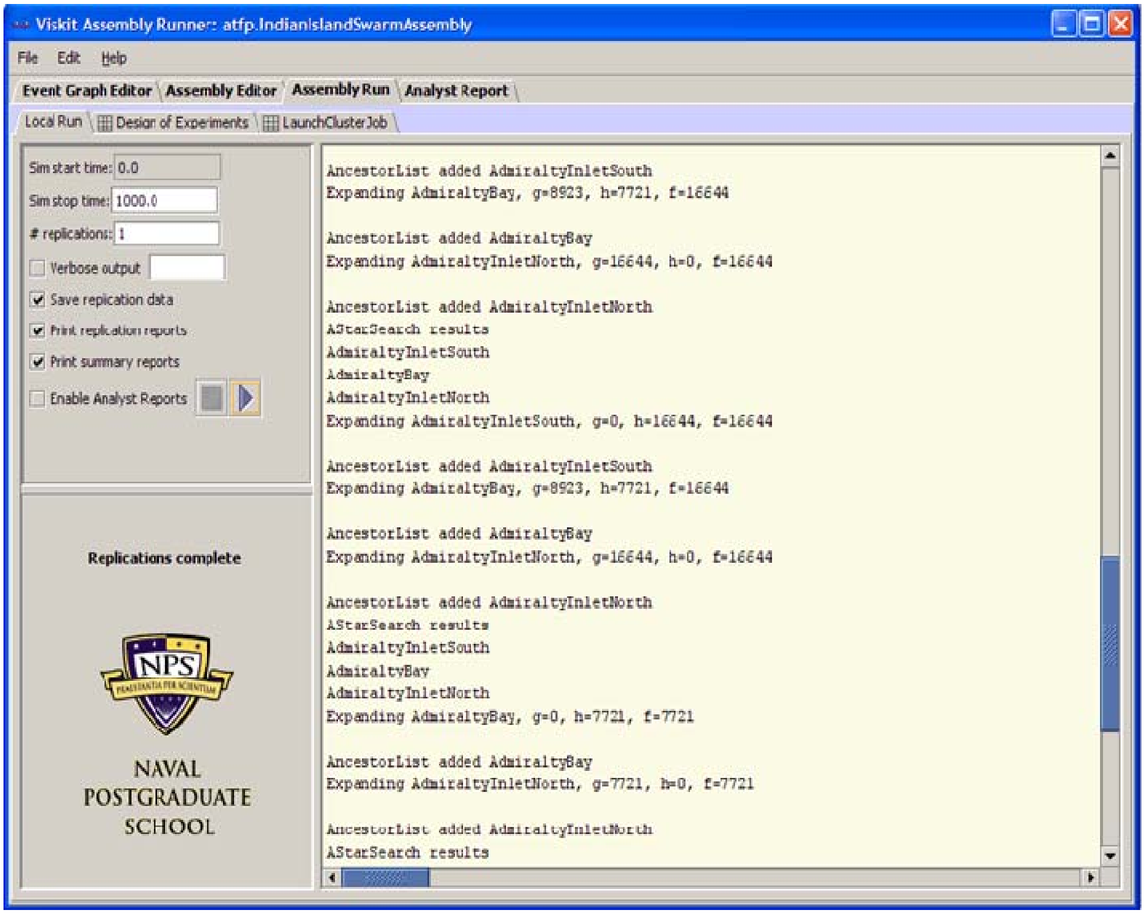

Figure 40. Viskit output window showing looping logic attempting to path find from Admiralty Bay.

A possible reason for this erroneous logic may be a statement in the A* search Java file that will not allow path finding if the next zone is considered a "dead end." A dead end is described in the code as a zone that contains no children or the child is the zone that the mover currently occupies. This should not be a restriction now that the nautical chart's parent-children relationships have been corrected to reflect two way movements. Figure 41 shows the "Dead End" code from the AStarSearch.java file located in the Diskit source code. It is this definition of dead end that may be causing the incorrect route planning. Follow-on work will be needed to confirm this suspicion and to complete simulation debugging for execution.

```
/**
 * Checks to see if the zone in question is a dead end
 *@param currZone the current zone being tested
 *@return deadEnd whether or not this is a dead end
 */
private boolean isDeadEnd(AStarZoneGeometry currZone) {
    boolean deadEnd = false;
    String[] children = currZone.getChildNames();
    for (String child : children) {
        if (isAncestor(child) && children.length == 1) {
            deadEnd = true;
        }
    }
    return deadEnd;
}
```

Figure 41. Code block from AStarSearch.java showing the dead end computations (Sullivan 2006).

When the DDG was hard coded to traverse the map directly to Admiralty Inlet South, another apparent bug surfaced. The code was modified to clear the A* zone list and then the destination zone was appended as the sole element in the list. When this was done the DDG traversed smoothly across the map with no looping logic. However, once that addition to the code was added, all of the threat craft initialized at a point well above the horizon. As the DDG transited the map, the threat craft remained clustered together in the sky. Modifications to the start zone in an attempt to hard code a starting zone failed to fix this error. I believe that there is a fault in a transform that is switching the –Z and Y axis but I have been unable to find it.

C. CONCLUSIONS

1. Training

Current training is insufficient because it does not address or assess a CSW gunner's ability to actually hit and disable a moving target. An assessment of the current standards for proficiency needs to be completed in order to ascertain whether 100 rounds of live fire every 8 months is sufficient to maintain proficiency in actual firing operations.

Current force protection requirements do not address realistic swarm training. Current force protection qualifications focus on protection in port and on boarding teams. Conclusion: A gap in training exists.

A proposed means of closing the current training gap is to develop and field augmented reality trainers such as AR-VAST. Additionally, smaller less expensive remote control targets could be used in the interim to improve CSW operator proficiency. One such target could be off the shelf remote controlled model boats. Many are 2-3 feet long and move at speeds in excess of 20 miles an hour. Since these remote control boats are designed to be used in close proximity of other remote controlled boats, de-conflicting radio channels for multiple boats would be simple. At prices as low as $40-50 a piece; crews could routinely fire on and destroy these boats. Given their small size and speed, these would prove to be very challenging targets for CSW operators and would no doubt create competition among gunners.

2. Current Weapons

Current fleet weapons are aging and were not initially designed to operate at sea. These are weapons developed for the army to counter human and lightly armored targets. They were not designed to stop or destroy boats made of wood or fiberglass. Punching a number of holes in a vehicle may be very effective in disabling it, but doing the same thing to an inherently buoyant object is far less useful. This leaves it up to the gunners to be skilled enough to hit either an engine or the driver in order to halt inbound craft. Conclusion: A gap in technology exists.

Proposed solutions to the current gap in technology are to employ, or at a minimum, investigate new systems such as General Dynamics XM307. A more immediate option is the use of incendiary rounds for current CSWs. While putting holes in a wooden boat may not be terribly effective, setting it on fire would be very detrimental to its operation. Additionally, in the event that a small boat was loaded with explosives or munitions incendiary rounds may prove extremely effective.

D. GOALS AND ACTUAL OUTCOMES

The following were my goals at the outset of this thesis. Many of the incomplete sections are also recommendations for future work.

- Analyze current training (complete)
- Assess if a training gap exists (complete)
- Analyze current weapons (complete)
- Assess if a technology gap exists (complete)
- Generate a swarm based scene for use in Savage Studio (complete)
- Run scenario and collect data on saturation of CSW gunners (incomplete)
- Collect data on detect to engage sequence (incomplete)
- Implement realistic event graph for target classification (incomplete)

VI. RECOMMENDED FUTURE WORK

The following items are identified as future work.

1. Savage Studio Force Protection Tool

The most important work that needs to be done is within the underlying code of the Savage Studio Force Protection simulation. The Savage Force Protection tool requires grooming in order to reach its full potential. Its outstanding potential is currently hampered by code problems that prevent it from operating correctly. The scale of this is quite large and I recommend it be left to professionals.

2. Work Within the Current Model

There are still numerous improvements that can be made to the current scenario. Making each watch stander on the DDG an independent sensor and adding line of sight from deck gunners to the target would vastly improve the output and aid in more detailed analysis. The communications messages from the DDG should be changed to reflect contact reports. A new event graph for threat assessment (using visual sensor and threat parameters) can be developed for more realistic classification by the DDG of visually acquired contacts. This would involve coding up a set of logic based on what does and does not constitute a threat and a human decision making study would be extremely useful in creating this logic. A simple but effective change would be to add more traffic to the scene. Currently there are only two sailboats and no ferries or other surface traffic. This is not necessarily representative of real world situations. Finally, a night time transit simulation is needed. However, the majority of previously mentioned items should be completed first.

3. Data Collection and Studies

There is a great deal of data that needs to be collected to improve future simulations and a number of studies that need to be conducted to aid in understanding the overall problem. Of extreme value would be a study evaluating CSW gunner's abilities to

engage moving targets. Additionally, work needs to continue on the AR-VAST system. Suitability studies need to be conducted on new systems such as the XM307 to evaluate whether they would make good additions to the current inventory or even replace older systems. Real world metrics need to be collected on current weapons so that accurate damage modeling can be accomplished. Finally, this information needs to be used to construct a classified scenario using real world data.

4. Investigation of Cost Effective Interim Solutions

All of the recommended work and changes will take time. However, the threat exists. For this reason, we must investigate novel solutions such as remote controlled speed boats, to increase training effectiveness until permanent solutions are found. Although the idea of firing CSWs at remote controlled speed boats may sound trivial, the ability to actually engage and destroy inexpensive small targets could greatly improve gunner target acquisition, communication, and accuracy.

LIST OF REFERENCES

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